CUTTING AND JOINING METALS IN CANADIAN UNDERGROUND COAL MINES: A REVIEW OF AVAILABLE TECHNOLOGY, INDUSTRY NEEDS AND RESEARCH OPPORTUNITIES.

FINAL REPORT
BY
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EXECUTIVE SUMMARY

Under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada, Robinson Dames & Moore has conducted a review of available technology, industry needs, and research opportunities for cutting and joining metals in Canadian underground coal mines, to accomplish the following objectives:

- Review of available technology for cutting and joining metals, that could find application in underground coal mines.
- Ranking of the various available technologies based on consideration of their strengths and weaknesses.
- Ranking of emerging techniques and technologies that could with research and development find application in underground coal mines, based on consideration of their strengths and weaknesses.
- Proposal of a program of research, development, and demonstration to bring the most promising techniques/-technologies to commercialization.
- Summarize existing regulations governing flame cutting and arc welding in Canadian underground coal mines.
- Review of existing industry needs and frequency of flame cutting and arc welding in Canadian underground coal mines.
- Identification of future industry needs in relation to cutting and joining metals.
- Comparison of current Canadian practices with those in selected foreign jurisdictions.

The study concludes that the need for flame cutting and arc welding effectively has been eliminated from underground coal mines in the United Kingdom and Alberta, and that their use in jurisdictions which permit such techniques (such as the United States and Nova Scotia) is a matter of operating convenience rather than an unavoidable existing need. Future industry needs for flame cutting and arc welding in Canadian underground coal mines could be obviated by application of sound engineering practices in the design and installation of underground mining equipment and facilities to ensure that they can be assembled from bolted or otherwise mechanically joined components which can be removed to the surface where welding can be performed more safely and effectively.

RÉSUMÉ ADMINISTRATIF

Sous l'égide du Centre canadien de la technologie des minéraux et de l'énergie et celle d'Énergie, Mines et Ressources Canada, Robinson Dames & Moore a mené une étude sur la technologie disponible, les besoins de l'industrie et les occasions de recherche dans le domaine du découpage et de l'assemblage de métaux dans les mines de charbon souterraines canadiennes, afin d'atteindre les objectifs suivants:

- Un examen de la technologie disponible pour le découpage et l'assemblage des métaux qui pourrait être mise en application dans les mines de charbon souterraines.

- Un classement des diverses technologies disponibles et fondé sur les points forts et les points faibles de chacune.

- Un classement des nouvelles techniques et technologies qui pourraient, si elles faisaient l'objet de recherche et de perfectionnement, trouver un domaine d'application dans les mines de charbon souterraines; il serait fondé sur les points forts et les points faibles de chacune.

- Une proposition pour un programme de recherche et de développement et une démonstration afin d'amener la commercialisation des techniques et des technologies les plus prometteuses.

- Résumer les règlements actuels régissant le découpage au chalumeau et la soudure à l'arc dans les mines de charbon canadiennes.

- Un examen des besoins actuels de l'industrie régissant le découpage au chalumeau et la soudure à l'arc dans les mines de charbon souterraines canadiennes.

- Une identification des besoins futurs de l'industrie concernant le découpage et l'assemblage des métaux.

- Une comparaison entre les pratiques courantes canadiennes et celles de juridictions étrangères prédéterminées.

L'étude conclut que le besoin en matière de découpage au chalumeau et de soudure à l'arc a été éliminé de façon efficace des mines de charbon souterraines au Royaume-Uni et en Alberta, et que leur usage dans certaines juridictions permettant ces techniques (comme les États-Unis et la Nouvelle-Écosse) est une question de mode pratique de fonctionnement plutôt que de besoin actuel et inévitable. On pourrait parer aux besoins futurs de l'industrie en matière de découpage au chalumeau et de soudure à l'arc dans les mines de charbon souterraines canadiennes par l'application de pratiques de génie éprouvées dans la conception et la pose d'équipement et d'installations souterrains d'extraction afin d'assurer qu'ils puissent être montés à partir d'éléments boulonnés ou mécaniquement assemblés d'une autre façon, pouvant être amenés à la surface là où la soudure peut être exécutée de façon plus sécuritaire et efficace.

TABLE OF CONTENTS

		Page
1.	INTRODUCTION	
1.1	STUDY OBJECTIVES	1
1.2	STUDY PROCEDURE	1
		1
2.	REVIEW OF AVAILABLE TECHNOLOGY	3
2.1	TECHNOLOGY AVAILABLE FOR CUTTING METALS: DESCRIPTION OF PROCESSES	3
2.1.1	Thermal Cutting	3
2.1.1.1	Oxygen-Fuel Gas Cutting	3
2.1.1.2	Air-Carbon-Arc Cutting	4
2.1.2	Mechanical Metal-Cutting Techniques	7
2.2	AVAILABLE TECHNOLOGY FOR JOINING METALS: DESCRIPTION OF PROCESSES	8
2.2.1	Welding Processes	8
2.2.1.1	Shielded Metal Arc Welding	8
2.2.1.2	Gas Metal Arc Welding	11
2.2.1.3	Oxygen-Fuel Gas Welding	12
2.2.1.4	Submerged Arc Welding	14
2.2.1.5	Thermit Welding	16
2.2.1.6	Other Available Welding Techniques	18
2.2.2	Soldering and Brazing	18
2.2.2.1	Soldering	18
2.2.2.2	Brazing	19
2.2.3	Mechanical Fastening	20
3.	RANKING OF AVAILABLE TECHNOLOGIES IN TERMS OF THEIR STRENGTHS AND WEAKNESSES	23
3.1	CONSIDERATION OF STRENGTHS AND WEAKNESSES OF AVAILABLE TECHNOLOGIES	23
3.1.1	Fire and Ignition Hazards	23
3.1.1.1	Metal-Cutting	24
3.1.1.2	Metal Joining	25
3.1.2	Fume, Dust, and Environmental Hazards	26
3.1.3	Versatility and Performance	29
3.2	RANKING OF AVAILABLE CUTTING AND JOINING TECHNOLOGIES	30
4.	REVIEW AND RANKING OF EMERGING TECHNIQUES AND TECHNOLOGIES	33
4.1	REVIEW AND DESCRIPTION OF EMERGING METAL-CUTTING TECHNIQUES	33
4.1.1	Laser Beam Cutting	33
4.1.2	Abrasive Water-Jet Cutting	33
4.1.3	Hydraulic Guillotine Metal-Cutting	34

TABLE OF CONTENTS (continued)

		Page
4.2	REVIEW AND DESCRIPTION OF EMERGING METAL-JOINING TECHNIQUES	36
4.2.1	Laser Beam Welding	36
4.2.2	Electron Beam Welding	37
4.2.3	Friction Welding	38
4.2.4	Flux-Cored Arc Welding	40
4.2.5	Adhesive Bonding	42
4.2.6	Other Emerging Techniques	44
4.3	RANKING OF EMERGING CUTTING AND JOINING TECHNOLOGIES	45
5.	PROPOSED PROGRAM OF RESEARCH, DEVELOPMENT, AND DEMONSTRATION	48
5.1	RESEARCH	48
5.2	DEVELOPMENT	48
5.3	DEMONSTRATION	50
6.	REGULATIONS GOVERNING FLAME CUTTING AND ARC WELDING IN CANADIAN UNDERGROUND COAL MINES, AND COMPARISON OF CANADIAN PRACTICES WITH THOSE IN SELECTED FOREIGN JURISDICTIONS	51
6.1	CANADA	51
6.1.1	Western Canada - Alberta	51
6.1.2	Eastern Canada - Nova Scotia	52
6.2	UNITED KINGDOM	53
6.3	UNITED STATES	55
7.	EXISTING AND FUTURE NEEDS AND FREQUENCY OF FLAME CUTTING AND ARC WELDING IN CANADIAN UNDERGROUND COAL MINES	58
7.1	EXISTING NEEDS AND FREQUENCY	58
7.2	FUTURE INDUSTRY NEEDS	59
8.	CONCLUSIONS	61
	APPENDIX A - Bibliography	

LIST OF FIGURES

Figure		Page
1	OXYGEN-FUEL GAS CUTTING	5
2	OXYGEN-ACETYLENE WELDING AND CUTTING SYSTEM	5
3	AIR-CARBON-ARC ELECTRODE HOLDER	6
4	SHIELDED METAL ARC WELDING	10
5	COMPONENTS OF A TYPICAL WELDING CIRCUIT FOR SHIELDED METAL ARC WELDING	10
6	GAS METAL ARC WELDING PROCESS	13
7	SCHEMATIC DIAGRAM OF GAS METAL ARC WELDING EQUIPMENT	13
8	OXYGEN-FUEL GAS WELDING	15
9	STRUCTURE OF THE OXYGEN-ACETYLENE FLAME	15
10	MANUAL SUBMERGED ARC WELDING GUN	17
11	SUBMERGED ARC WELDING PROCESS	17
12	BRAZE WELDING PROCESS	21
13	BASIC COMPONENTS OF ABRASIVE WATER JET CUTTING SYSTEM	35
14	SELF-CONTAINED HYDRAULIC GUILLOTINE-TYPE CUTTER	35
15	ELECTRON BEAM GUN	39
16	ELECTRON BEAM WELDING MACHINE	39
17	TYPES OF JOINTS COMMONLY MADE BY FRICTION WELDING	41
18	SELF-SHIELDED FLUX CORED ARC WELDING	43
19	GUN FOR SEMIAUTOMATIC SELF-SHIELDED FLUX CORED ARC WELDING	43

LIST OF TABLES

Table		Page
1	POSSIBLE PARTICULATE CONTAMINANTS FROM WELDING FUMES . .	28
2	RANKING OF AVAILABLE CUTTING TECHNIQUES	31
3	RANKING OF AVAILABLE JOINING TECHNIQUES	32
4	RANKING OF EMERGING METAL-JOINING TECHNIQUES AND TECHNOLOGIES	46

1. INTRODUCTION

1.1 STUDY OBJECTIVES

The objectives of this study of available technology, industry needs, and research opportunities, in relation to cutting and joining of metals in Canadian underground coal mines are as follows:

- Review of available technology for cutting and joining metals, that could find application in underground coal mines.
- Ranking of the various available technologies based on consideration of their strengths and weaknesses.
- Ranking of emerging techniques and technologies that could with research and development find application in underground coal mines, based on consideration of their strengths and weaknesses.
- Propose a program of research, development, and demonstration to bring the most promising techniques/technologies to commercialization.
- Summarize existing regulations governing flame cutting and arc welding in Canadian underground coal mines.
- Review existing industry needs and frequency of flame cutting and arc welding in Canadian underground coal mines.
- Identify future industry needs in relation to cutting and joining metals.
- Compare current Canadian practices with those in selected foreign jurisdictions.

1.2 STUDY PROCEDURE

A computer-assisted bibliography search was conducted for published literature relevant to available techniques for cutting and joining metals in underground coal mines and to emerging techniques and technologies. The

data bases that were searched included NTIS, COMPENDEX, MINTEC, and Welda-search. A bibliography of literature relevant to this study was compiled of 104 references and is included as Appendix A.

In addition to the bibliography search, extensive correspondence and telephone conversations were entered into with potential sources of information relevant to the objectives of this study. Robinson Dames & Moore evaluated the applicability of the various cutting and joining technologies to underground coal mines based on data obtained by contacting officials in the Canadian coal industry, correspondence with Canadian underground coal mine regulatory authorities, review of relevant literature, and by reference to Robinson Dames & Moore's experience with the requirements and constraints of underground coal mining.

On December 11/12, 1984, Robinson Dames & Moore met with Mr. G.A. Haslett, the CANMET Scientific Authority for this project, to discuss the project requirements and to review progress. The meeting was found by Robinson Dames & Moore to be extremely beneficial to its conduct of the study.

2. REVIEW OF AVAILABLE TECHNOLOGY

2.1 TECHNOLOGY AVAILABLE FOR CUTTING METALS: DESCRIPTION OF PROCESSES

The techniques currently available for cutting metals in underground coal mines can be grouped into two fundamentally different categories, namely, thermal cutting and mechanical cutting. The commercial availability of a particular technology has been considered in this study as being determined, for purposes of characterization, by the extent of its use in the mining industry as a whole rather than by the current status of its specific applicability to Canadian underground coal mines. Thermal cutting techniques such as oxygen-fuel cutting and air-carbon-arc cutting are available that could find applications in underground coal mines which are located in jurisdictions in which such "open-flame" or "electric-arc" processes are permitted under mining safety regulations. Mechanical cutting techniques that are available and find suitable applications in underground coal mines include various processes involving sawing, chiseling, shearing, or abrasive grinding.

2.1.1 Thermal Cutting

2.1.1.1 Oxygen-Fuel Gas Cutting

The oxygen-fuel methods available for thermal cutting of ferrous metals rely upon the removal of rapidly oxidized or melted metal from the cut, by means of a high-velocity stream of oxygen directed at the pre-heated metal. Local pre-heating is necessary to initiate and sustain the cutting process. When heated to above approximately 870°C (1600°F) ferrous metals oxidize very rapidly when exposed to a high-pressure stream of oxygen, in an intense exothermic reaction. Cutting takes place as the heated metal is oxidized or melted and is blown away by the high-pressure stream of oxygen, as depicted in Figure 1.

The heat necessary for pre-heating in oxygen-fuel cutting is provided by a neutral flame at the cutting torch tip, for which acetylene is commonly used as a fuel, especially in portable, manual applications. The main functions performed by the pre-heat flames are to pre-heat the metal to the ignition temperature, maintain a protective envelope around and to pre-heat the center jet of oxygen, to maintain the reaction temperature to the new metal constantly being presented to the center jet of oxygen as the cut progresses, and to penetrate any foreign substances on the metal's surface such as rust, scale, dirt, etc.

A variety of other fuel gases including propane, hydrogen, natural gas and ethylene are also used in portable or machine-mounted cutting torches (Stewart, 1981). Figure 2 outlines the basic components of a typical, portable, oxygen-fuel cutting system utilizing acetylene and a hand-held cutting torch.

2.1.1.2 Air-Carbon-Arc Cutting

The air-carbon-arc technique for thermal cutting of metals is a process in which metal within the cut is melted by the heat of an electric arc from a carbon electrode and the molten metal is blown away by a high-velocity stream of compressed air. The hand-held air-carbon-arc cutting torch is an adaptation of the standard single carbon arc welding torch. The carbon electrode holder has passages so that a high-velocity stream of air can be directed along the axis of the electrode. The cutting procedure when using an electric air-carbon-arc cutting torch is similar to that for oxygen-fuel cutting. The electrical power supply for air-carbon-arc cutting is direct current, with current settings ranging from 80 to 1,400 amps depending on the diameter of the electrode used. Figure 3 outlines the basic components of a hand-held, air-carbon-arc cutting torch electrode holder.

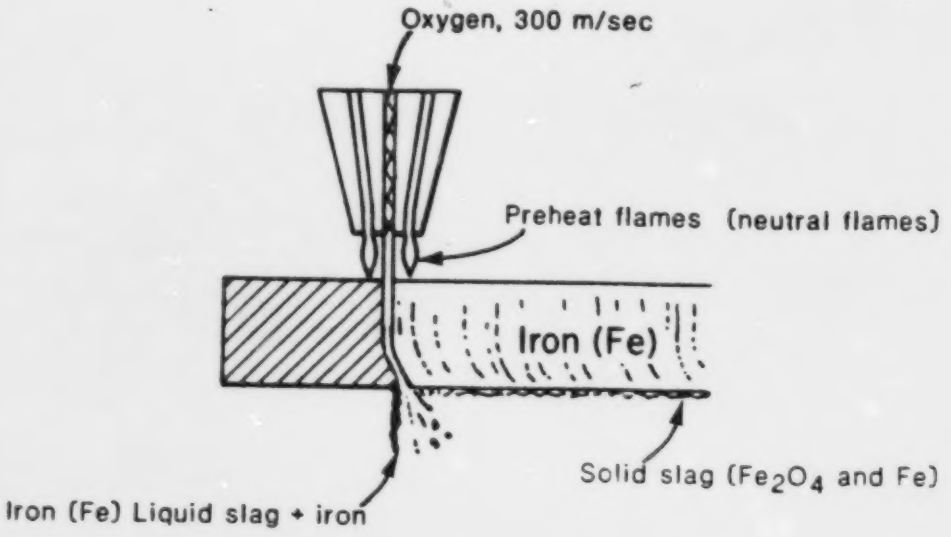


FIGURE 1 - OXYGEN-FUEL GAS CUTTING

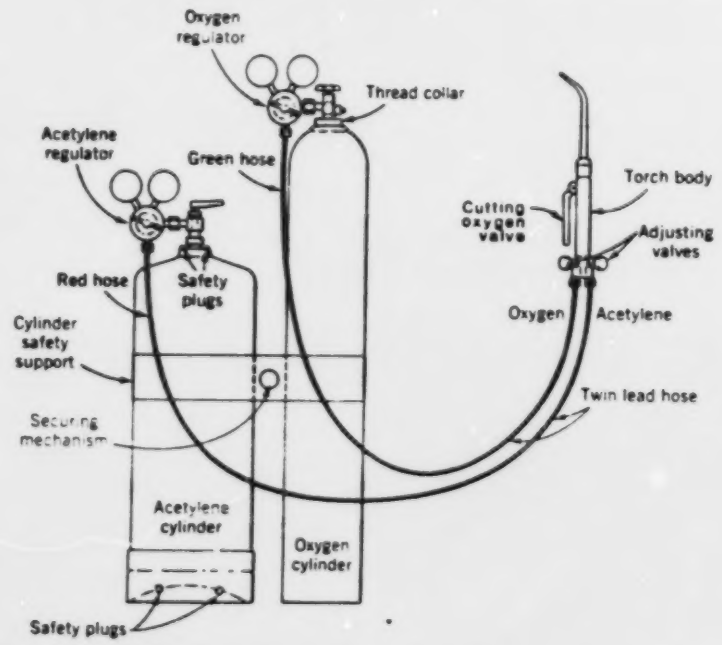


FIGURE 2 - OXYGEN-ACETYLENE WELDING AND CUTTING SYSTEM

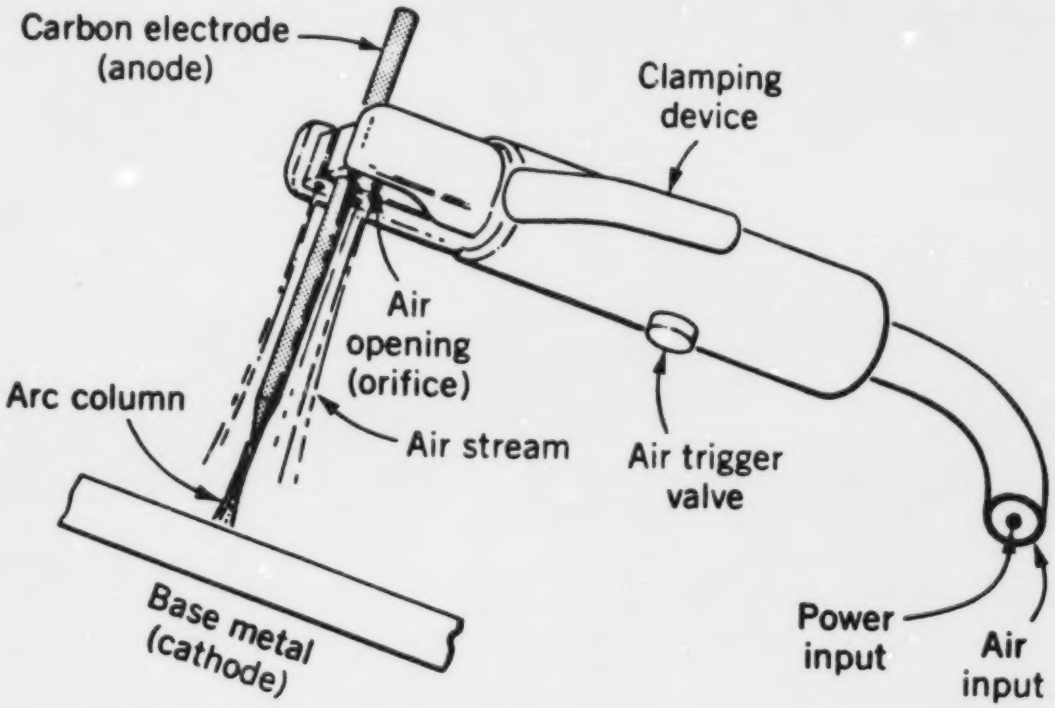


FIGURE 3 - AIR-CARBON-ARC ELECTRODE HOLDER

2.1.2 Mechanical Metal-Cutting Techniques

Metal-cutting saws, either powered or hand-operated, are available for applications involving cutting metal bars, rods, and pipes to length. Stationary, powered hack-saws and band saws are usually used for routine cut-off of shop work having a diameter of up to 250 mm. A hand-held hack-saw is commonly used for general work such as severing small-cross-section pieces or cutting sheet metal parts to shape. Portable, powered hack saws are also available, as are powered circular saws utilizing high-speed abrasive cut-off wheels. Hand shears or snips are used for cutting thin sheet-metal to shape. Straight snips are used for all straight-line work, and for large-radius external curves; bent snips are useful for cutting small external and all internal curves.

Stationary shearing machines are useful for cutting large pieces of sheet metal. A manually operated shearing machine consists simply of a fixed blade and a cropper, operated by a long handle so as to obtain the advantage of a long lever. Shearing machines provide considerable saving of time over sawing methods, however the metal is not cut squarely, except on very thin sheet-metal, so that it is not possible to work to accurate dimensions without subsequent filing or grinding.

In many cases, neither a hack-saw nor a shearing machine is suitable for cutting heavy-gauge metal. Chiseling is the method of mechanical metal cutting which often is then used. The flat hand chisel, and the portable, pneumatically powered chisel, are most widely applicable. The flat chisel has a broad cutting edge and can be used for cutting out sheet metal, cutting off rods and bars, and for chipping broad surfaces. Chisels are also used for a variety of purposes such as are found in repair work, for example, removal of rivet heads or the cutting of nuts and bolts which are rusted fast.

2.2 AVAILABLE TECHNOLOGY FOR JOINING METALS: DESCRIPTION OF PROCESSES

Metal-joining techniques that are commercially available and which could find application in underground coal mines have been reviewed by Robinson Dames & Moore in terms of three broad categories of joining technologies. These have been considered to include welding, soldering/brazing, and mechanical fastening. It is worth noting that a survey of welding techniques conducted by Olson and Mueller (1977), reported the following percentage distribution of the use of various welding processes in the mining industry: shielded metal arc welding - 72 percent, gas metal arc welding - 17 percent, oxygen-fuel gas welding - 10 percent, and submerged arc welding - 1 percent.

2.2.1 Welding Processes

Technologies for joining metals by welding, that are commercially available in relation to possible application in underground coal mines, join metals by melting and fusing them together, usually with the addition of a welding filler metal. The joints produced are commonly as strong as the metals joined. A concentrated heat is applied to the joint area and is of a sufficiently high temperature to melt the base metals (the metals being joined) as well as the filler metal. The term arc welding refers to welding processes that use an electric arc as the source of heat to melt and join metals. Oxygen-fuel gas welding comprises a group of welding processes that use the heat produced by a gas flame for melting the base metal and, if used, the filler metal.

2.2.1.1 Shielded Metal Arc Welding

Shielded metal arc welding, sometimes referred to as flux-shielded arc welding, or stick welding, is one of the simplest, and most versatile arc welding processes. The process uses a covered, consumable electrode consisting of a core wire around which a clay-like mixture of silicate

binders and powdered fluxes and additives (such as fluorides, carbonates, oxides, metal alloys, and cellulose) is extruded and baked to produce a dry, hard concentric electrode covering. The core conducts the electric current to the arc and provides filler metal to the joint. The electrode covering performs several functions. It must stabilize the arc, provide a gas and a flux layer to shield the arc and metal from atmospheric contamination, control weld-metal reactions, and permit alloying elements to be added to the weld metal (Houldcroft, 1977). The control of moisture in electrode coverings is necessary to limit the hydrogen in weld metal.

The electrode is clamped in an electrode holder which is connected to the electrical power source by a cable. The arc is initiated by touching the electrode tip against the work and then withdrawing it. The heat produced by the arc melts the base metal in the immediate area, as well as the electrode metal core and the electrode covering. A portion of the covering material constituents is oxidized by the intense heat of the arc, providing a gaseous shield (mostly carbon dioxide) around the arc that prevents oxygen and nitrogen in the air from combining with the molten metal to cause a poor-quality weld. The alloy produced from the molten base metal, core wire, and metal powders in the electrode covering freezes to form the weld. The principal aspects of the process are illustrated in Figure 4, while Figure 5 outlines the basic components of a typical welding circuit for shielded metal arc welding. Either alternating current or direct current is utilized, with the electrode either positive or negative polarity in the case of direct current.

The electrical current used for manual operation usually ranges from 15 to 500 amps. The voltage used ranges from 14 to 40 volts, with lightly covered electrodes employing voltages in the lower portion on the range (Little, 1977). Covered electrodes typically are produced in straight lengths of 230 to 460 mm. Variations in the amount of slag and shielding provided by different types of covered electrodes are designed to influence welding characteristics as necessary for the specific work. Electrodes that

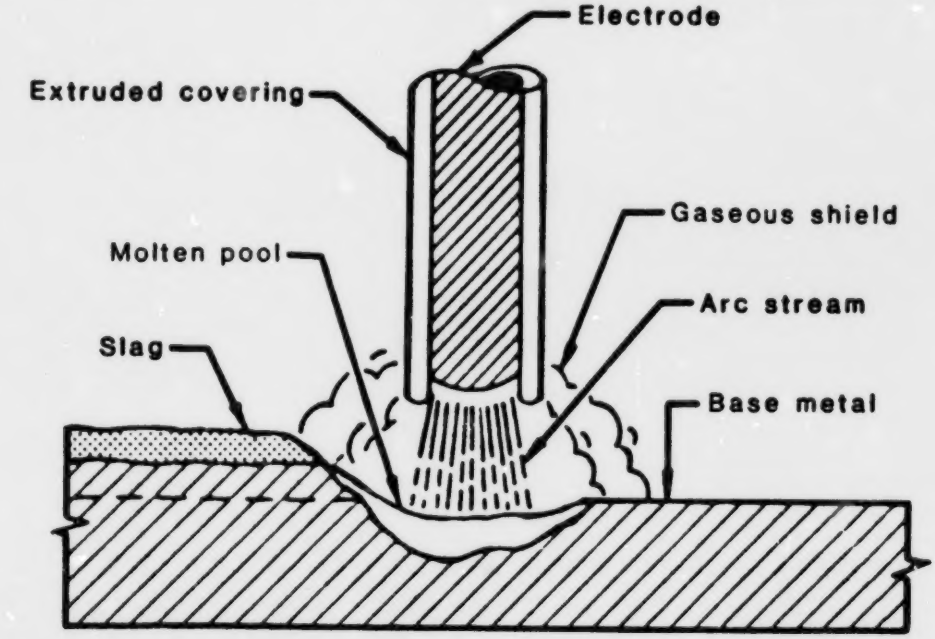


FIGURE 4 - SHIELDED METAL ARC WELDING

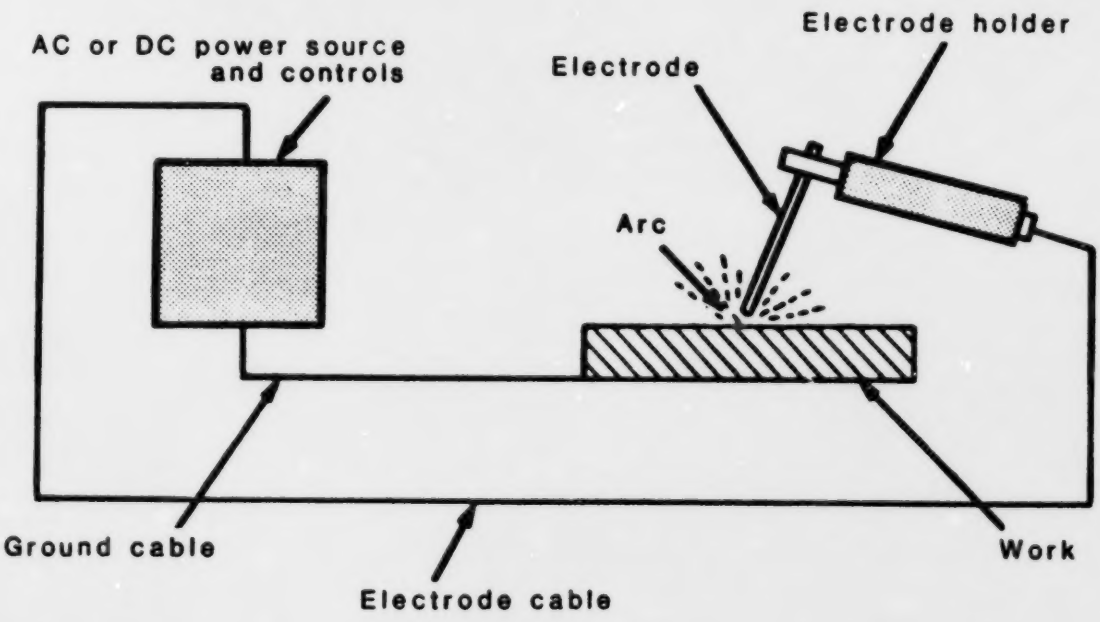


FIGURE 5 - COMPONENTS OF A TYPICAL WELDING CIRCUIT FOR SHIELDED METAL ARC WELDING

create a heavy slag typically carry high currents and have high metal deposition rates, and are best suited for making large beads in the flat position. Electrodes that develop a gaseous arc shield and produce a light layer of slag carry lower amperage and have lower deposition rates and, because they produce a smaller weld pool, are better suited to making welds in the vertical or overhead positions.

2.2.1.2 Gas Metal Arc Welding

Gas metal arc welding is a process in which a continuous wire is utilized as a consumable, bare electrode for which shielding is provided by a supply of inert or other suitable gas. The shielding gas protects the arc and weld zone from air and also promotes the arc characteristics desired. Welders can work continuously with gas metal arc welding since the wire electrode is fed continuously and only fatigue or changing position requires the arc to be interrupted. Gas metal arc welding applications typically employ direct current reverse polarity (electrode positive). This type of electrical connection provides a stable arc, smooth metal transfer, relatively low spatter loss, and good weld bead characteristics for a wide range of currents.

The major shielding gases used are argon, carbon dioxide, and helium, or a combination of these three gases. The shielding gas affects the electrode burn-off rate, type of metal transfer, and penetration characteristics. Mixtures of oxygen, carbon dioxide, and argon are generally suitable for the welding of mild steel (Little, 1973). Argon can be used generally to weld all metals. Typical flow rates and nozzle diameters for shielded metal arc welding would be 1.1 to 1.7 cubic metres per hour for nozzles of 12 to 19 mm; with a lower flow rate common for ferrous metals (Houldcroft, 1977). An illustration of the gas metal arc welding process is shown in Figure 6.

Figure 7 is a schematic diagram outlining the fundamental elements of a typical system of gas metal arc welding equipment. Gas metal arc welding equipment comprises a welding gun, a power supply, and a wire-feed system which pulls the wire electrode from a spool and feeds it through the welding gun. For high-current applications, a source of cooling water may be required for the welding gun in applications employing above about 250 amps. Gas metal arc welding guns available for manual welding are usually shaped in the form of a pistol, or similar to an oxygen-fuel torch, with electrode wire fed through the barrel or handle. Welding current is transmitted to the continuous wire electrode as the wire passes through a copper contact tube within the welding gun.

Gas metal arc welding is utilized particularly in high-production welding operations. All commercially important metals such as carbon steel, stainless steel, aluminum and copper can be welded in all positions, by choosing the appropriate shielding gas, electrode wire, and welding conditions.

2.2.1.3 Oxygen-Fuel Gas Welding

Oxygen-fuel gas welding comprises welding techniques that use a fuel gas combined with oxygen to produce a flame having sufficient energy density, and temperature, to melt the base metal. Oxygen-fuel gas welding commonly utilizes acetylene as the fuel gas but, more recently, other fuel gases such as methylacetylene propadiene (MAPP) have found acceptance. Manual welding methods are most commonly used and require minimal equipment. A suitably sized torch, hoses, regulators, oxygen in a pressurized cylinder, acetylene in a pressurized cylinder, welding rods, goggles, and protective clothing are the principal items needed to perform oxygen-acetylene gas welding. The basic components of the oxygen-fuel gas welding system are largely similar to those utilized for oxygen-fuel cutting, as shown in Figure 2.

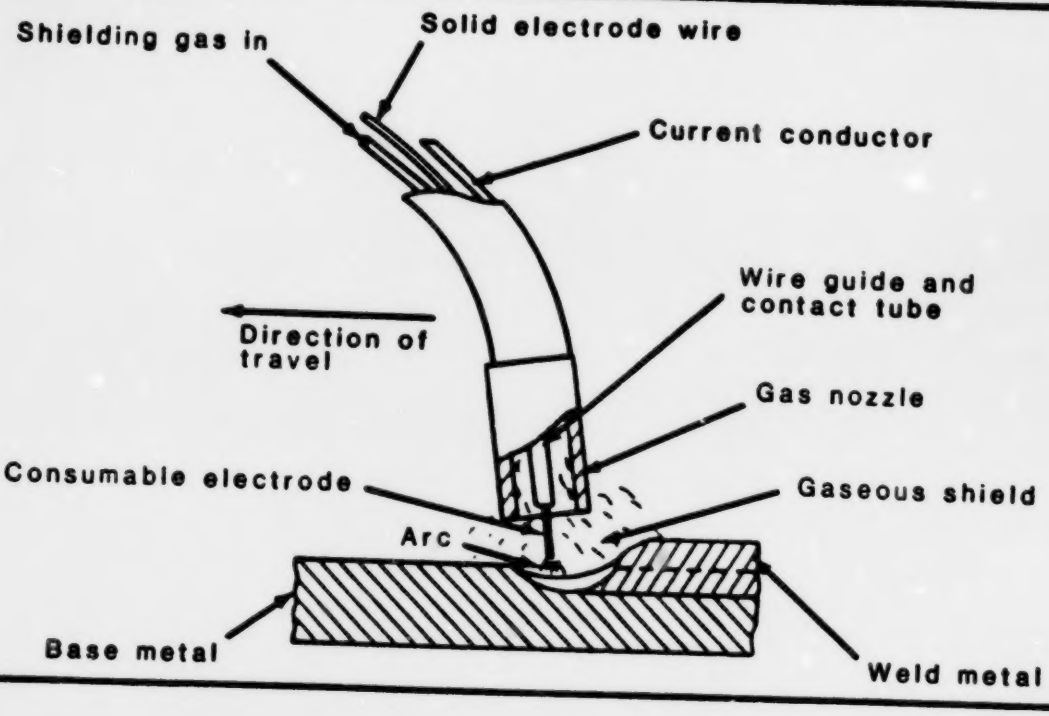


FIGURE 6 - GAS METAL ARC WELDING PROCESS

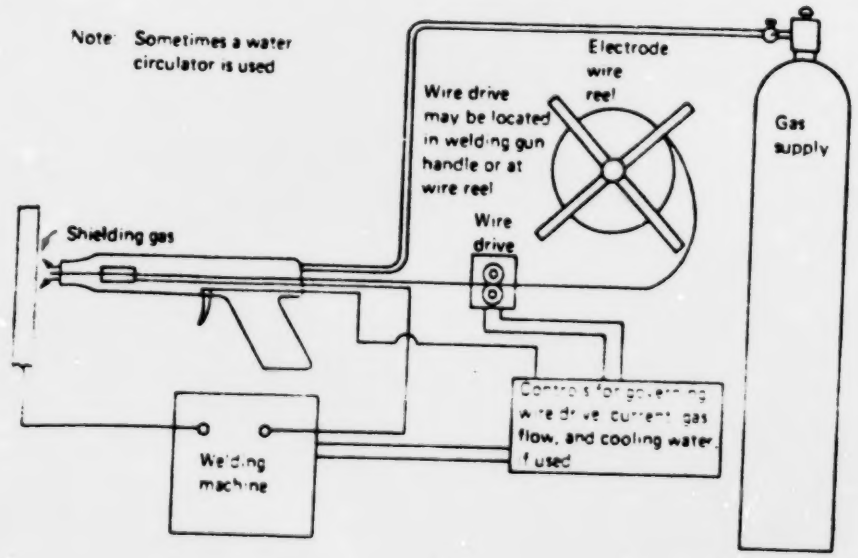

Note: Sometimes a water circulator is used
Electrode wire reel
Wire drive may be located in welding gun handle or at wire reel
Gas supply
Shielding gas
Wire drive
Welding machine
Controls for governing wire drive current, gas flow, and cooling water, if used

FIGURE 7 - SCHEMATIC DIAGRAM OF GAS METAL ARC WELDING EQUIPMENT

Oxygen-fuel welding can be accomplished either with or without the addition of filler metal, although use of filler metal offers the advantage of greater versatility in joint design. Ferrous metals are welded using a neutral flame, the secondary combustion of which protects the molten weld metal sufficiently to provide shielding from the surrounding air. The fundamental processes of oxygen-fuel gas welding are shown in Figure 8. The structure of the oxygen-acetylene flame as used in the welding is shown in Figure 9. The function of the welding torch is to bring together correct volumes of the fuel gas and oxygen, mix them efficiently, and pass them through a nozzle to form a flame with characteristics suitable for welding. Oxygen-fuel gas welding is very versatile, can weld most common metals, and the equipment involved is easily portable.

2.2.1.4 Submerged Arc Welding

Submerged arc welding is similar to gas metal arc welding in terms that a continuously-fed consumable wire electrode is utilized. Rather than employing a shielding gas, however, submerged arc welding relies on the arc and molten metal being shielded by an envelope of molten flux and a layer of unfused granular flux particles. Powdered flux is fused during welding in approximately the same weight proportion as the electrode wire melted and is left on the weld bead as a layer of glassy slag. Flux not fused during the welding operation is recovered for use again, but care must be taken to ensure that such flux is not contaminated. Filler metal is provided by the consumable electrode and sometimes by a supplementary welding rod or other metallic addition.

In submerged arc welding, the end of a continuous bare wire electrode is inserted into a mound of flux that covers an area or joint to be welded. An arc is initiated, causing the base metal, electrode, and flux in the immediate vicinity to melt. The electrode is advanced in the direction of welding and mechanically fed into the arc while granular flux is steadily added (American Welding Society, 1976). Semi-automatic welding using the

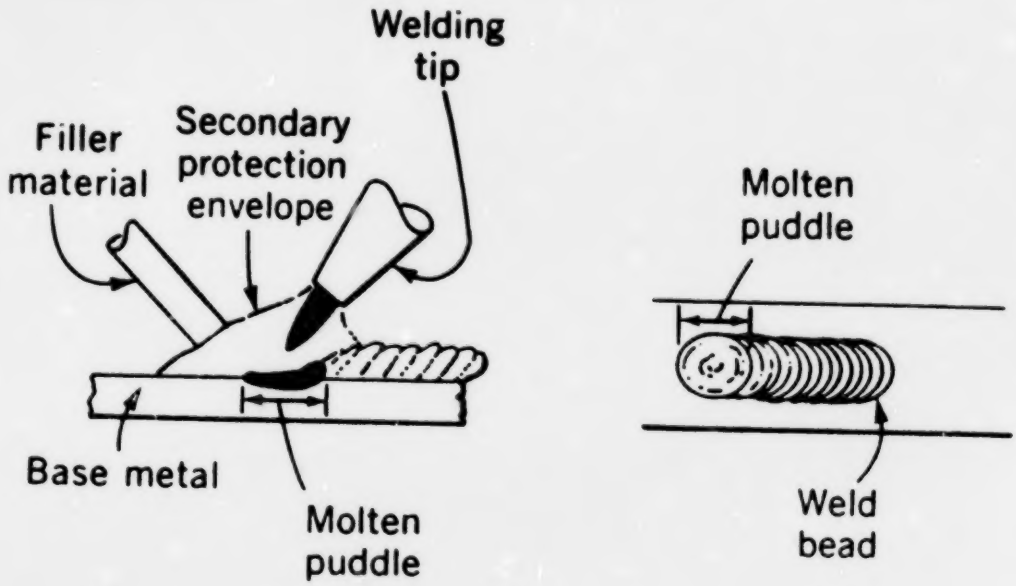


FIGURE 8 - OXYGEN-FUEL GAS WELDING

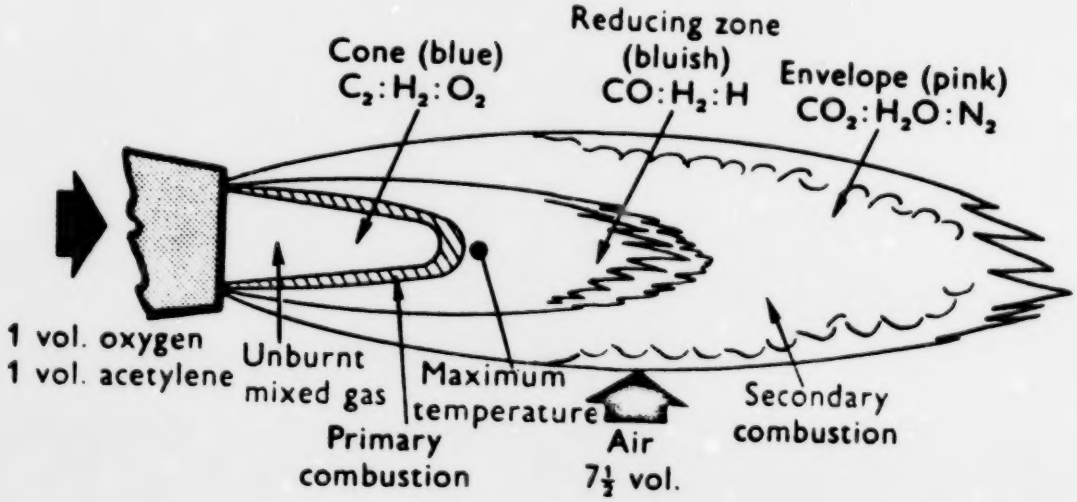


FIGURE 9 - STRUCTURE OF THE OXYGEN-ACETYLENE FLAME

submerged arc technique utilizes a hand-held welding gun, through the nozzle of which both flux and continuous wire electrode are fed. Manual submerged arc welding can be used generally whenever shielded metal arc welding is used, but is largely limited to the flat welding position. Figure 10 is an illustration of the manual submerged arc welding gun, and Figure 11 outlines the submerged arc welding process.

2.2.1.5 Thermit Welding

Thermit welding is a technique which uses heat from exothermic chemical reactions between metal oxides and reducing agents to produce molten, super-heated metal that flows into a mold and between two parts of a joint to produce a weld. Although the main application of the process is for joining steels, non-ferrous reactions are feasible and copper and copper-based alloys have been used for joining large-cross-section copper conductors. The first and most widely employed use of thermit welding is for joining rails, although it has also been used in heavy construction, ship-building, joining reinforcing bars, and for repair welding (Houldcroft, 1977).

Thermit welding of steel typically utilizes a mixture of iron oxides and aluminum oxide. A charge of 1,000 grams of thermit produces roughly 475 grams of slag, 525 grams of molten iron, 180,000 calories of heat energy, and temperatures of up to 2450°C.

Thermit welding is suited to the welding of joints with large, compact cross-sections. A pre-heating torch is often required in thermit welding of large parts, to dry the mold and heat the joint to a suitable temperature, because the super-heated metal from the thermit reaction in some cases is not sufficient to provide all the heat necessary for welding. The apparatus used in thermit welding consists of a mold around the joint to be welded and into which the super-heated molten metal flows by gravity, and a conical crucible containing the thermit powder and positioned over the joint. The

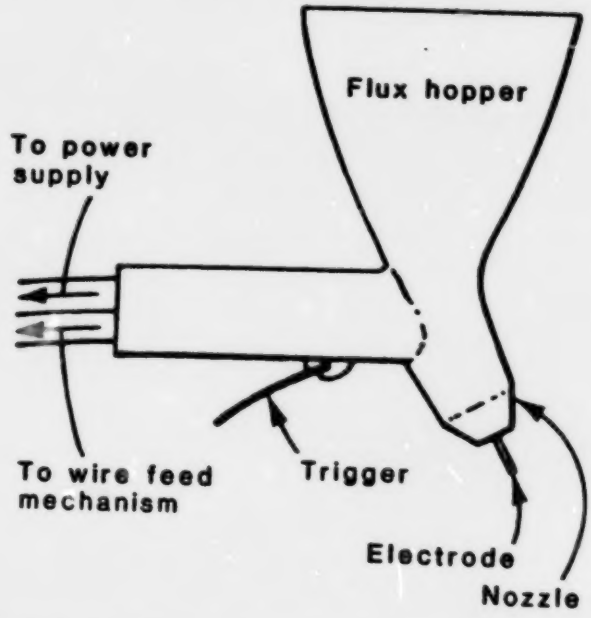


FIGURE 10 - MANUAL SUBMERGED ARC WELDING GUN

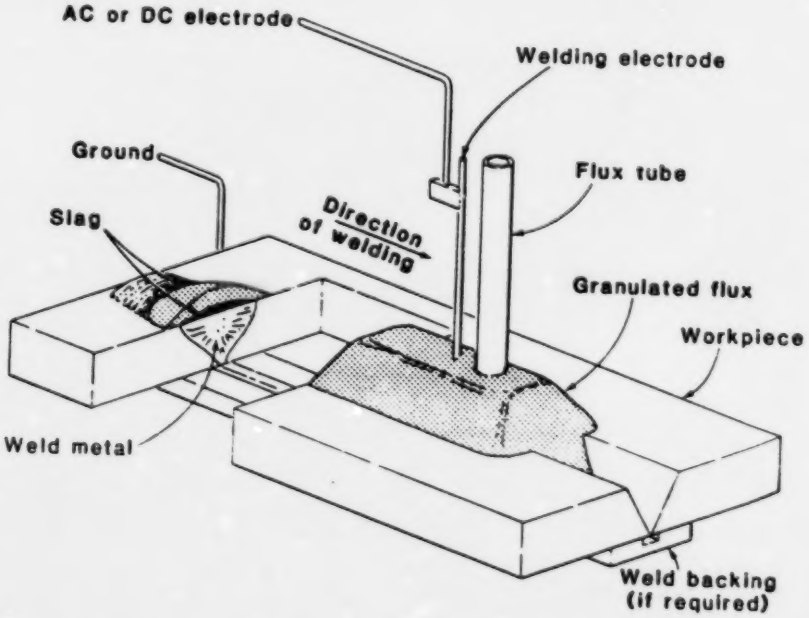


FIGURE 11 - SUBMERGED ARC WELDING PROCESS

super-heated molten metal produced by a thermit reaction flows into the gap between the pieces to be joined with sufficient heat to melt both faces of the base metal. When the filler metal has cooled, all unwanted excess metal may be removed by thermal cutting, machining, or abrasive grinding.

2.2.1.6 Other Available Welding Techniques

Several available welding techniques are mentioned briefly in this section, which represent metal-joining techniques that are suitable for use almost exclusively in manufacturing or specialty fabrication shop settings. Robinson Dames & Moore considers that these "other available welding techniques" generally lack the applications flexibility and portability necessary for use in underground coal mines. Such techniques would include resistance spot, resistance seam, projection, flash, gas tungsten arc, plasma arc, capacitor-discharge stud, electroslag, electrogas, and forge welding.

For centuries, forge welding was the only method of welding known, as practiced by the blacksmith in joining iron, and commonly used to make welded chain links. In forge welding, the parts to be joined are usually heated to over 1000°C until they are plastic, and then they are hammered together. Oxide and scale are fluid at the temperatures employed and the hammering is done in such a way as to squeeze this out of joint and permit contact of clean metal surfaces. Forge welding is suitable for joining wrought iron and, with precise temperature control and the addition of fluxes, to carbon steel. Forge welding has been almost entirely supplanted by more versatile, modern welding techniques.

2.2.2 Soldering and Brazing

2.2.2.1 Soldering

Soldering involves heating a joint to a suitable temperature and using a filler metal which melts below 450°C. The solder is melted by the heat of

joint by capillary action. Heat is required to melt the solder and to promote the action of a flux on the metal surface which permits the molten solder to wet and flow into the joint. A successfully soldered joint requires shaping the parts to fit closely together, cleaning the surfaces to be joined, applying a flux, assembling the parts, and applying the heat and solder.

2.2.2.2 Brazing

Brazing is the joining of metals through the use of heat and a filler metal whose melting temperature is above 450°C, but below the melting temperature of the metals being joined (American Society for Metals, 1980). Brazing does not melt the metals being joined, but creates a metallurgical bond between the filler metal and the surfaces of the joint. The molten filler metal is drawn through the joint by capillary action. Design of brazed joints requires consideration of good fit, proper clearances, and thorough cleaning of the surfaces to be joined, to ensure that capillary action is not impeded.

A coating of flux is applied to the joint area, preferably immediately after cleaning, to shield the cleaned metal surfaces from the air, thus preventing oxide formation. The flux will also dissolve any oxides that may already be present on the metal (those that were not completely removed in the cleaning process). Prior to application of heat, the parts to be brazed are positioned or assembled to hold the joint together while the permanent joint is being made.

Brazing is accomplished by applying heat broadly to the base metals. Entire small assemblies are commonly heated to the brazing temperature, while brazing a large assembly will usually involve heating a broad area around the joint. The heating method most commonly used in brazing of small assemblies is the oxygen-fuel torch. Following brazing, flux residues which are chemically corrosive must be removed.

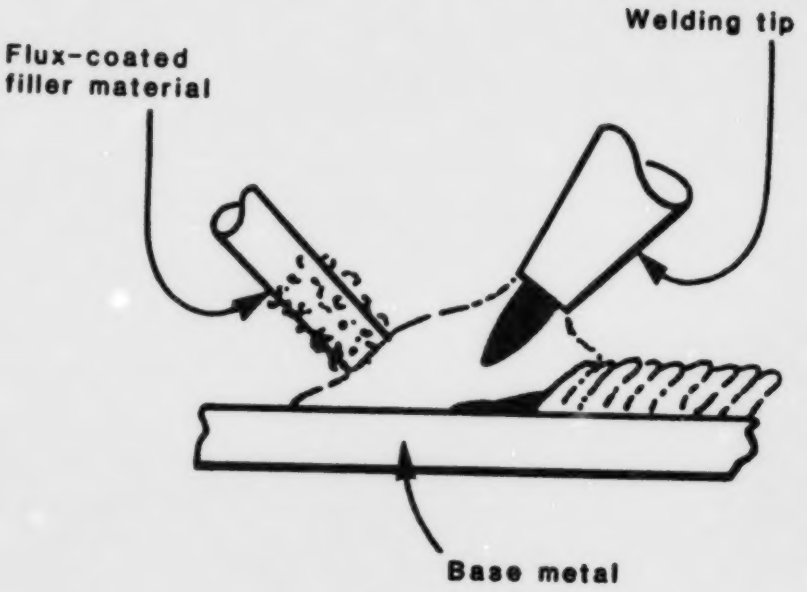
Brazing is arbitrarily distinguished from soldering by the filler metal melting temperature. Braze welding is differentiated from brazing because the filler metal is deposited in a groove or fillet exactly at the point where it is to be used and capillary action is not a factor. The braze welding process is illustrated in Figure 12.

Brazing filler metals are composed of alloys containing various proportions of silver, copper, zinc, cadmium, phosphorous and, in some cases, tin or nickel. In manual brazing applications, using an oxygen-fuel torch, filler metal is added to the joint in the form of cut lengths or coils of wire composed of the desired brazing alloys.

2.2.3 Mechanical Fastening

Available techniques for joining metals by means of mechanical fasteners find application in underground coal mines in the form of riveted and bolted joints to connect metal plates or structural members, bolted joints to secure equipment components, and specialized threaded fasteners and clamping systems. Although riveted joints using hot-driven rivets once had been one of the most extensively used methods of joining metal plates and structural members, the few remaining applications of riveted joints in underground coal mines are limited to pre-assembled components or pressure vessels that have been manufactured with riveted construction, and to cold methods of riveting such as blind riveting ("pop-rivets") which have found application in light-duty fastening of sheet metal.

Bolted joints to secure metal plates, structural members, and equipment components must be based on proper engineering design to ensure structural integrity. High-strength bolts are used that are made from a heat-treated steel having a suitably high tensile strength. Joints made from high-strength bolts are of the friction or bearing type (Hoadley, 1964). In friction-type joints the bolt is tightened until it is stressed nearly to



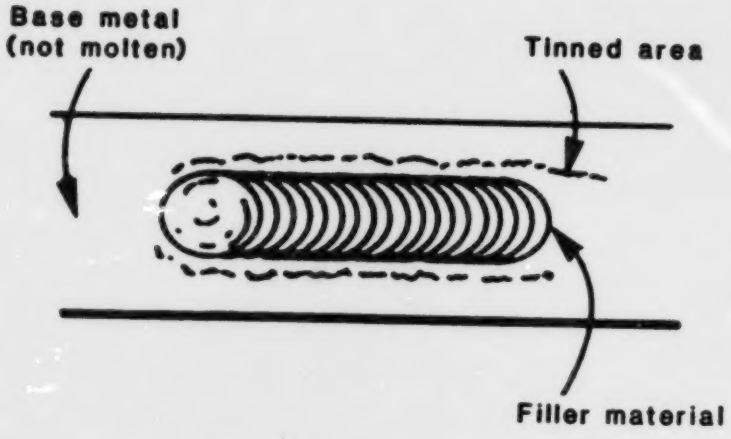


FIGURE 12 - BRAZE WELDING PROCESS

the proof load; creep may reduce this load slightly later. The clamping force produced by this high tension in the bolt is great enough so that the full load on the joint is transmitted by friction between the pieces being joined. This type of joint gives good service under impact, vibratory loading, or loading involving stress fluctuation or reversal. The contact surfaces of a friction joint must be free from rust, paint, or galvanizing. As the name implies, the load in a bearing-type joint is transmitted by bearing between joint members as well as by the clamping action of the high-strength bolts. High-strength bolts should be tensioned by using a calibrated torque wrench.

Specialized systems of fastening by means of threaded clamps are available that enable pipes, beams, timber, floor gratings, etc., to be secured to steelwork without the need for on-site drilling or welding (Lindapter, 1984). The range of applications for which such fasteners are available is quite extensive and includes connections of girder to girder, angle to angle, channel to channel, girder to angle, and girder to channel structural joints. In addition, clamping systems are available for pipe fixings, pressure vessel ends, and punched or expanded-metal floor gratings. Specialized bolting systems are available which are designed for making attachments or repair work to steel or similar structures which are only accessible from one side. Pieces of from 7 mm to 70 mm in thickness can be joined by this system using bolts of from 10 mm to 24 mm in diameter.

3. RANKING OF AVAILABLE TECHNOLOGIES IN TERMS OF THEIR STRENGTHS AND WEAKNESSES

3.1 CONSIDERATION OF STRENGTHS AND WEAKNESSES OF AVAILABLE TECHNOLOGIES

Robinson Dames & Moore has evaluated the various available technologies for cutting and joining metals in terms of their strengths and weaknesses in relation to the constraints, hazards, and requirements peculiar to applications in underground coal mines. The factors considered in evaluating the strengths and weaknesses of each of the available technologies can be grouped into four major categories:

- Degree of safety in relation to fire and ignition hazards,
- Creation of fume, dust, and environmental hazards,
- Physical compatibility with underground coal mine work place locations, and
- Relative performance.

3.1.1 Fire and Ignition Hazards

Application of available technology for cutting and joining metals to underground coal mines requires that the cutting or joining technique must be capable of being made compatible with the fire and ignition hazards present in the underground coal mine environment. The extreme consequences that can result from these hazards demand consideration of the potential for cutting and joining techniques to ignite combustible materials such as loose coal, timber, coal dust, conveyor belting, grease and oil, and explosive mixtures of coalbed methane in air. Furthermore, the extent to which a cutting or joining technique comprises a source of additional combustible material such as acetylene or propane fuel gas must be recognized.

The importance of fire and ignition hazards associated with metal cutting and joining techniques in use in underground coal mines in the United States is illustrated in a report by McDonald and Baker (1975) which indicated that welding and cutting was the ignition source for an increasing percentage of fires. The data indicated that in the period 1953 to 1961, welding and cutting was the ignition source of eight fires, representing 1.7 percent of the total number of fire occurrences studied for that period. Corresponding data for the period 1962 to 1969 showed 15 fires, or 3.75 percent, and for the period 1970 to 1977 showed 11 fires representing 8.5 percent.

3.1.1.1 Metal-Cutting

Thermal cutting techniques present obvious hazards for ignition of explosive atmospheres of methane in air. The pre-heat flame of the oxygen-fuel gas cutting torch and the electric arc of the air-carbon-arc cutting technique constitute open ignition sources having temperatures and durations far in excess of those necessary to ignite an explosive mixture of methane in air. The hot slag and molten metal expelled from the cut by either of the two available thermal cutting techniques constitutes a hazard of both fire and methane/air ignition, and large hot metal pieces severed by such techniques can be of sufficient mass to initiate smouldering if allowed to come into contact with combustible materials. Oxygen-fuel gas cutting presents the further hazard of introducing pressurized cylinders of fuel gas (commonly acetylene) and oxygen into the mine, with the potential for leaks associated with faulty valves or hoses, and for sudden massive releases of the cylinders' contents in the event of accidents that could physically damage the cylinders.

Fire and ignition hazards associated with mechanical metal-cutting techniques are generally of a lesser severity than those of thermal metal-cutting techniques. The potential for incendive sparking exists with high-speed abrasive cut-off saws as well as with generally most other

abrasive grinding techniques and, to a lesser extent, with chiseling techniques. Powered, mechanical, metal-cutting equipment such as powered hack-saws and band-saws can constitute a fire and ignition hazard if powered by electric motors (which could be made flameproof, or substituted with pneumatic or hydraulic motors) or if high-speed cutting is performed in a manner which could allow the workpieces or the saw blades to overheat.

3.1.1.2 Metal Joining

All of the available welding techniques discussed in Section 2.2.1, rely upon high-temperature and high-energy-density heat provided by an open flame, electric-arc, or super-heated molten metal and, because of this, are fundamentally incompatible with the fire and ignition hazards of underground coal mines. In addition to the heat sources used in welding techniques, other fire hazards associated with welding include welding spatter of molten metal and red-hot slag, introduction of combustible fuel gases (in the case of oxygen-fuel gas welding), electrical fire and ignition hazards of arc-welding power supplies, and the initiation of coal dust smouldering by the careless placement of hot workpieces or of hot discarded ends of shielded metal arc welding rods.

The oxygen-fuel gas welding and the submerged-arc welding techniques typically produce considerably less welding spatter than do shielded metal arc and gas metal arc welding techniques. Oxygen-fuel gas welding and thermit welding techniques utilize heat sources that are somewhat less concentrated, and thus result in greater overall heating of the workpieces, than the arc-welding techniques. Virtually all of the welding techniques require considerable abrasive grinding and chiseling in the course of joint preparation and slag removal.

Brazing techniques that could find application in underground coal mines typically utilize the oxygen-fuel gas torch as a source of heat and are largely similar to oxygen-fuel gas welding techniques in terms of fire

and ignition hazards. Soldering techniques for small applications such as electrical connections, copper tubing, and light sheet metal can utilize an electrical resistance-heated soldering iron as a heat source, thus eliminating the need for open flames and fuel-gas cylinders, although introducing electrical fire and ignition hazards associated primarily with the soldering iron's power supply. Soldering and brazing techniques involve overall heating of the workpieces, although the technique known as braze welding is considered to heat the workpieces to a lesser extent. The risk of initiating coal dust smouldering exists if hot workpieces, the hot soldering iron, or molten excess solder or brazing filler metal are handled carelessly.

Mechanical fastening techniques available for joining metals generally do not constitute a problem in terms of fire and ignition hazards, because they do not utilize high-temperatures as do welding, soldering, and brazing techniques. The principal fire and ignition risks associated with mechanical fastening techniques arise from the need in such applications to drill holes in the work pieces in which to insert the mechanical fastening device. Electrically powered drills introduce fire and ignition hazards normally associated with electrical equipment in underground mines. Substitution of hydraulically or pneumatically powered drills can be utilized which eliminate the electrical fire and ignition hazards. It should be recognized that high-speed drilling of holes in metals can result in elevated temperatures of the drill bit and of small workpieces, and could contribute to the risks of initiation of smouldering coal dust.

3.1.2 Fume, Dust, and Environmental Hazards

Thermal techniques of cutting metals, and welding techniques of joining metals, create signficant volumes and concentrations of potentially harmful fumes and dust. To prevent the inhalation of fumes, gases, and particulate

matter, a positive ventilation system must be used. The nature, type, and magnitude of fume and gas exposure will determine the type, location, and capacity of air removal methods needed (American Society for Metals, 1983).

Surfaces coated with paint containing chrome, lead, or zinc can produce toxic fumes when subjected to the high heat of welding or thermal cutting (Derby, 1982). Grease that may be present on metal pieces being cut or joined in repair work can contribute significantly to fume generation. Chlorinated degreasing solvents retained on work pieces can let off vapors when heated that can be broken down by ultraviolet radiation from arc welding to produce phosgene gas and hydrochloric acid, which are highly toxic (National Institute for Occupational Safety and Health, 1979). Parts that have been degreased with chlorinated solvents should not be welded or cut until all degreasing compound vapors are completely removed (Lincoln Electric Company, 1973).

At least 20 different types of particulate contaminants have been identified as possible of being produced by welding and thermal metal-cutting, as reported by Derby (1982) and listed in Table 1. Techniques for cutting and joining metals that involve high temperatures, fluxes or other materials containing fluorine compounds, or that involve toxic metals such as zinc, lead, beryllium, cadmium, or mercury may require that hose masks or self-contained breathing equipment be used (Lincoln Electric Company, 1973). The United States Bureau of Mines has investigated fumes generated by shielded metal arc welding with selected stainless steel electrodes and has designed, assembled, and calibrated a welding fume generation and collection apparatus for use in measuring welding fume generation rates (McIlwain and Neumeier, 1982). Particular attention has been focused on the potential for the chromium contained in stainless steels to produce welding fumes that can be carcinogenic.

Table 1

Possible Particulate Contaminants from Welding Fumes

Particulate	Effect	TLV-TWA,[1] mg/m^3
Aluminum oxide	Aluminosis	10.0
Peryllium dust	Berylliosis; lesion of the skin, liver, kidneys, spleen, and lymph nodes	0.002
Cadmium dust	Plumonary edema	0.05
Carbon black	Anthracosis	3.50
Chromium	Bronchospasm, bronchitis, edema, hypersecretion, asthma	0.5
Copper fumes	Nausea, vomiting, metal fume fever, ulceration of the cornea	0.2
Fluorides	Change in bone structure, respiratory and other problems	2.50
Iron oxide	Siderosis	5.0
Lead	Cramps, nausea	0.15
Manganese	Total disablement	1.0
Mercury	Kidney damage, vomiting, diarrhea, gingivitis	0.05
Molybdenum	Bronchial and alveolar irritation, liver and kidney problems	5.0
Nickel metal	Cancer	1.0
Nickel sulfide	do	1.0
Silicates:		
Iron	Pneumoconiosis, respiratory insufficiency	10.0
Sodium	do	10.0
Tin oxide	Stannosis	2.0
Titanium dioxide	Fibrosis	10.0
Vanadium pentoxide	Conjunctivitis, pharyngitis, bronchopneumonia, chronic bronchitis	0.5
Zinc oxide	Zinc chills	5.0
Asbestos:[2]		
Amosite	Asbestosis, cancer	0.5
Crocidolite	do	0.2
All other	do	2.0

[1] American Conference of Government Industrial Hygienists. Threshold Limit Values for Chemical Substances in Workroom Air. ACGIH, Cincinnati, Ohio, 1980, 93 pp. TLV-TWA (threshold limit values/time-weighted averages) are the concentration levels of airborne contaminants to which nearly all workers can be exposed for a normal 7- or 8-hour workday, or 40-hour workweek, without adverse effect. These values should be used as guides in the control of health hazards, not as fine lines between safe and dangerous concentrations.

[2] TVL-TWA for asbestos is given in number of fibers greater than 5 um in length per cubic centimeter of air.

Shielded metal arc welding using cellulose-coated electrodes, gas metal arc welding in which carbon dioxide is used as a shielding gas, air-carbon-arc cutting techniques, and oxygen-fuel gas cutting techniques, have the potential to introduce carbon dioxide and carbon monoxide into the mine atmosphere. Gas metal arc welding and thermit welding techniques generally do not utilize fluxes and, in that regard, can be considered to contribute less to fume hazards than shielded metal arc, submerged arc, and oxygen-fuel gas welding techniques.

The oxygen-fuel gas torch, when fueled by acetylene and adjusted for a neutral flame, utilizes oxygen from the atmosphere to complete the combustion that occurs in the outer envelope of the flame. Of the 2.5 parts of oxygen needed for acetylene to burn completely, about 1.5 comes from the surrounding air and 1.0 part from feed oxygen (Stewart, 1981). It should be recognized, therefore, that the oxygen-fuel gas torch can contribute to the creation of an oxygen deficient atmosphere.

Environmental hazards of noise, ultraviolet radiation, and heat are characteristic of welding and thermal cutting techniques. Mechanical fastening techniques for joining metals, and mechanical cutting techniques, pose an environmental hazard primarily from excessive noise and from danger of eye injury by flying metal particles. The welding or cutting arc should never be observed at close quarters with unprotected eyes, and can result in various degrees of eye burn that, although they do not usually cause permanent injury, can be very painful for several days after exposure. Ultraviolet energy from arc welding and air-carbon-arc cutting operations produces a skin burn, which, like a sun-burn, is not immediately apparent.

3.1.3 Versatility and Performance

Several important factors must be considered by which available techniques for cutting and joining metals can be evaluated in terms of their relative versatility and performance characteristics. Physical factors to

be considered would include physical compatibility with underground coal mine workplace locations, portability of equipment and power supplies, adequacy of the finished joint in terms of strength and reliability, and requirements for elaborate joint preparation. Additional factors to be considered would include operator skill requirements, versatility in relation to the types of metal cutting and joining tasks required, cutting or joining speed, and susceptibility of the metal to cracking caused by alteration of metallurgical properties in the heat affected zone. Set-up time required, applications flexibility, fixturing cost, joint repair flexibility, cleanliness requirements, slag removal requirements, and initial equipment cost are of particular importance.

3.2 RANKING OF AVAILABLE CUTTING AND JOINING TECHNOLOGIES

Based on consideration of their relative strengths and weaknesses, the available technologies for cutting and joining metals have been ranked in terms of their characteristics in respect of three categories of major factors, namely safety and health, versatility, and performance. Available cutting techniques are ranked in Table 2, and available joining techniques are ranked in Table 3. The various techniques are ranked for each factor considered, by means of ranking scores that range from one to five, and for which a score of one indicates that the technique has characteristics that are most favorable (considerable strengths) and a score of five indicates that the technique has characteristics that are most unfavorable (considerable weaknesses).

Table 2

Ranking of Available Cutting Techniques

Safety & Health	Oxygen-Fuel Gas Cutting	Air-Carbon Arc Cutting	Hand Sawing	Powered Sawing	High-Speed Abrasive Sawing	Hand-Powered Shearing	Hand Chiseling	Powered Chiseling
Fire Risk	5	4	1	2	3	1	1	1
Ignition Risk	5	5	1	3	4	1	2	2
Fumes, Dust, & Environmental Factors	5	4	1	1	3	1	1	2
	15	13	3	6	10	3	4	5
Versatility								
Applications Flexibility	1	1	4	5	4	5	3	2
Workplace Location/Portability	3	5	1	3	2	1	1	2
Required Equipment, & Power, Gas & Air Supplies	5	4	1	2	3	1	1	3
	9	10	6	10	9	7	5	7
Performance								
Speed of Cutting Cutting	1	1	5	4	2	4	5	3
Tolerances	3	3	2	1	1	3	5	5
Metal Thickness or Toughness Limitations	1	1	5	4	3	5	4	4
	5	5	12	9	6	12	14	12
Totals	27	28	21	25	25	22	24	24

Table 3

Ranking of Available Joining Techniques

Safety & Health	Shielded Metal Arc Welding	Gas Metal Arc Welding	Oxygen-Fuel Gas Welding	Submerged Welding	Thermit Welding	Souldering	Brazing	Mechanical Fastening
Fire Risk	4	4	5	3	4	2	3	1
Ignition Risk	5	5	5	5	5	3	5	1
Fumes, Dust, & Environmental Factors	5	4	5	3	2	2	3	1
	14	13	15	11	11	7	11	3
Versatility								
Applications Flexiblity	1	1	2	3	4	5	4	4
Workplace Location/Portability	2	4	5	3	5	1	3	1
Required Equipment, & Power Gas & Air Supplies	2	5	4	2	4	1	3	1
	5	10	11	8	13	7	10	6
Performance								
Time Required for Set-up, Joining, & Subsequent Treatment	1	1	2	2	3	3	5	4
Joint Preparation Requirements	1	1	1	2	4	5	5	3
Joint Strength & Metallurgical Effects	1	1	1	1	2	5	4	3
	3	3	4	5	9	13	14	10
Totals	22	26	30	24	33	27	35	19

4. REVIEW AND RANKING OF EMERGING TECHNIQUES AND TECHNOLOGIES

4.1 REVIEW AND DESCRIPTION OF EMERGING METAL-CUTTING TECHNIQUES

4.1.1 Laser Beam Cutting

Laser beam cutting is a thermal cutting process which utilizes, as its source of heat, a concentrated coherent light beam which impinges on the workpiece to be cut. Metal is removed from the cut by a combination of melting and evaporation, although the assistance of a gas jet often is used to promote effective cutting. The gas used may be inert, to provide a smooth clean cut, or reactive, such as oxygen to speed the cutting process by means of an exothermic reaction similar to that which occurs in oxygen-fuel gas cutting of steel. A laser beam provides very high energy density and, consequently, high-speed cutting is attained with a very narrow kerf and heat-affected zone (American Welding Society, 1976). The laser beam cutting equipment is extremely costly compared to oxygen-fuel gas cutting equipment, and involves sophisticated, fixed installation and power supplies as are compatible with fabrication shop applications.

The most important utilization of laser beam cutting is in the cutting of titanium alloys of approximately 13 mm or less in thickness. The primary hazards in laser beam cutting are eye damage, skin burns, respiratory system damage from vaporized metal, and electric shock (American Society for Metals, 1983).

4.1.2 Abrasive Water-Jet Cutting

Equipment for abrasive water-jet cutting has been developed by Fluid Engineering Products Limited, England, from work carried out at British Hydromechanics Research Association (BHRA), Cranfield, in high-pressure water cutting techniques. The primary advantage of abrasive water jet

cutting is that it is a non-thermal and spark-free method of cutting. The technique can be used safely in explosive atmospheres, can cut steel without altering the material properties, and can be used to cut steel or reinforced concerete structures where environmental considerations prohibit the use of other methods (Fluid Engineering Products Limited, 1984).

The technique utilizes a patented abrasive jet cutting head, which is mounted on a high-pressure water-jetting gun. Abrasive feed to the cutting head is in the form of a water-based slurry, mixed and pumped to the cutting head by a pneumatically or hydraulically powered slurry mixing and pumping unit. High-pressure water is supplied through a hose to the cutting head by a high-pressure pump, at a required output of 42 liters per minute at a pressure of 70,000 kPa. The abrasive used is a cheap copper slag, which is non-toxic, and of a grit size of 2.0 to 0.2 mm. Cutting rates in 38-mm-thick mild steel plate are reported to be 60 mm per minute; and less than three minutes cutting time is required for cutting 50-mm-diameter mild steel bar. A schematic diagram of the basic components of the system is shown in Figure 13.

4.1.3 Hydraulic Guillotine Metal-Cutting

Self-contained, portable, hydraulic guillotine-type cutters have been developed as an alternative to sawing, chiseling, and thermal cutting techniques for applications on wire rope, round bar, chain, and electrical cable. Maximum capabilities of these cutters, sold under the trade name of ENERPAC, are advertised approximately as follows (Applied Power Inc., 1983):

> steel wire rope - 31 mm, copper or aluminum wires or bars -31 mm, soft steel bolts - 31 mm, reinforcing bar - 25 mm, bare copper or aluminum wire strand - 50 mm, telephone or power cable -85 mm, and alloy chain - 12 mm.

Figure 14 illustrates the general configuration of a self-contained, hydraulic guillotine-type cutter capable of severing 31-mm-diameter wire rope.

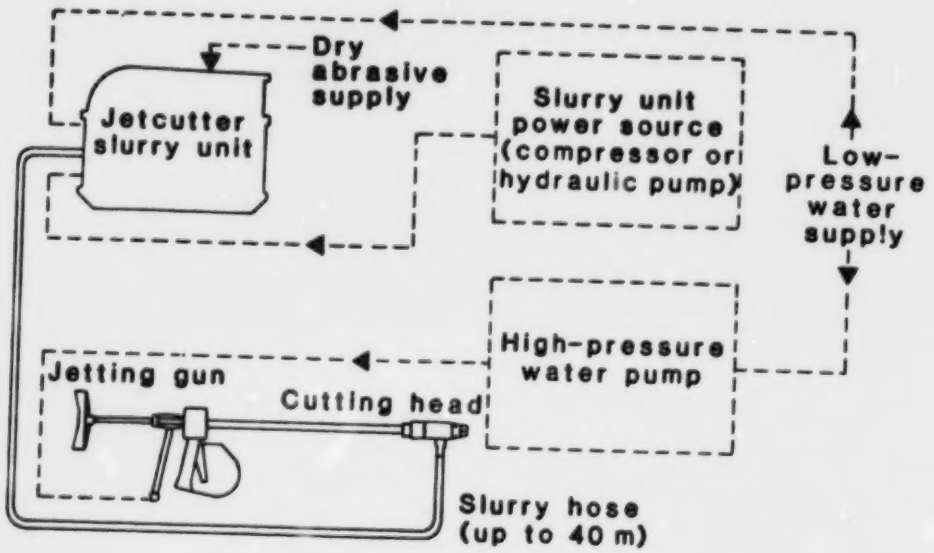


FIGURE 13 - BASIC COMPONENTS OF ABRASIVE WATER JET CUTTING SYSTEM

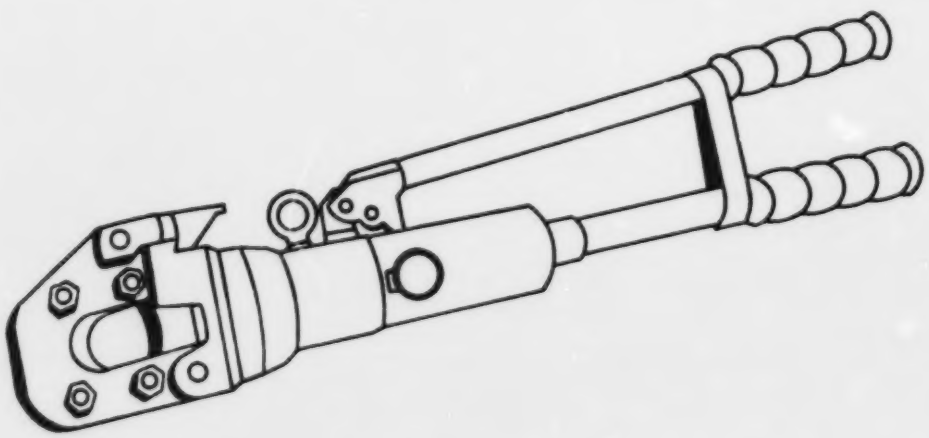


FIGURE 14 - SELF-CONTAINED HYDRAULIC GUILLOTINE-TYPE CUTTER

4.2 REVIEW AND DESCRIPTION OF EMERGING METAL-JOINING TECHNIQUES

4.2.1 Laser Beam Welding

Multi-kilowatt carbon dioxide gas laser systems have been developed that produce a beam of infra-red light which can be focused to provide power densities of 10 kW/mm^2 or greater. This provides the high-power carbon dioxide laser with deep penetration welding capability. Laser beam welding has been used successfully to join a variety of metals including low alloy and stainless steels, and is a high-speed process ideally suited to automation. The particular advantages of laser beam welding include very low heat input into the workpiece, exceptional cleanliness, the ability to weld without filler metal, use of a simple square butt joint design, and high speed (National Materials Advisory Board, 1982).

Thick-section laser beam welding is achieved by focusing a high power laser beam onto the surface of the metal. This focused, highly collimated source of heat evaporates the metal and creates a "keyhole", or metal-vapor-filled cavity, through the thickness of the workpiece. Surrounding this keyhole is the weld pool, a volume of molten metal in dynamic equilibrium with the metal vapor. As the workpiece is moved, melting takes place at the leading edge of the weld pool and solidification occurs to the rear (Metzbower, Moon, and Fraser, 1982). It has been noted that, although laser welding systems are cumbersome and costly, compared to conventional welding systems, they have been proven to be reliable in industrial environments (Allbright, 1982).

Operation of laser welding systems presents several significant hazards that are peculiar to such systems and are in addition to the ordinary hazards of thermal welding techniques. The additional hazards associated with laser beam welding techniques can be summarized as follows:

- Eye damage including burns of the cornea or retina, or both
- Skin burns
- Respiratory system damage due to evolution of hazardous materials during the beam-workpiece interaction
- Electrical shock
- Chemical hazards
- Cryogenic coolants

4.2.2 Electron Beam Welding

Electron beam welding is defined by the American Welding Society as a process that produces coalescence of metals by the heat obtained from a concentrated beam of high-velocity electrons impinging upon the surfaces to be joined. The beam of electrons is produced and accelerated by a electron gun, which typically comprises an emitter, a bias electrode, and an anode, with auxiliary mechanical and electrical components which may include beam alignment, focus, and deflection coils. A simplified representation of an electron beam gun is shown in Figure 15.

The electron beam welding process can be used to weld almost any metal. Steel up to 100 mm, aluminum up to 150 mm, and copper up to 25 mm in thickness, and many other metals from foil to plate are weldable in one pass (American Welding Society, 1976). The electron beam welding process involves a fairly sophisticated equipment installation which is largely stationary in a shop or manufacturing setting because of the equipment mass and precise tooling required. The electron beam welding process for the girth welding of large-diameter pipelines (greater than 450 mm O.D.) is being developed for off-shore laybarge pipewelding (Manuel, 1981).

Electron beam welding has several major advantages. It produces deep, narrow, and almost parallel-sided welds with low total heat input and comparatively small heat affected zones. Electron beam welding generally is performed in a hard vacuum (pressure of 0.13 to 133 mPa), but the process can be adapted to weld in soft vacuum (pressure of 0.13 to 13 Pa) or at atmospheric pressure. The basic equipment required includes a vacuum

chamber, controls, an electron beam gun, a power supply, an optical viewing system or tracking device, and work handling equipment. An example of an electron beam welding machine arrangement is shown in Figure 16.

The special potential dangers associated with electron beam welding equipment are: electric shock, X-radiation, fumes and gases, and damaging visible radiation. The equipment operates with high voltage that can cause fatal injury, and which requires that the machines be well insulated. The X-rays generated by an electron beam welding machine are produced when high-velocity electrons impinge upon the workpiece or strike gas molecules or metal vapor in the work chamber. Substantial radiation shielding consisting of lead lining of the work chamber for vacuum-type machines, or thick walls of high-density concrete for non-vacuum machines. Non-vacuum and medium-vacuum electron beam welding machines are capable of producing ozone and oxides of nitrogen, as well as other types of airborne contaminants, in concentrations well above acceptable levels and require proper techniques of exhaust and area ventilation.

4.2.3 Friction Welding

Friction welding is a technique in which the heat for welding is produced by direct conversion of mechanical energy to thermal energy at the interface of the workpieces without the application of electrical energy, or heat from other soures to the workpieces. Friction welds are made by holding a non-rotating workpiece in contact with a rotating workpiece under constant or gradually increasing axial loading until the interface reaches welding temperature, and then stopping rotation to complete the weld (American Society for Metals, 1983). The temperature at the joint interface does not reach the melting point of either workpiece, beacuse the metallurgical bond is achieved by diffusion, rather than fusion (Ellsworth, 1978).

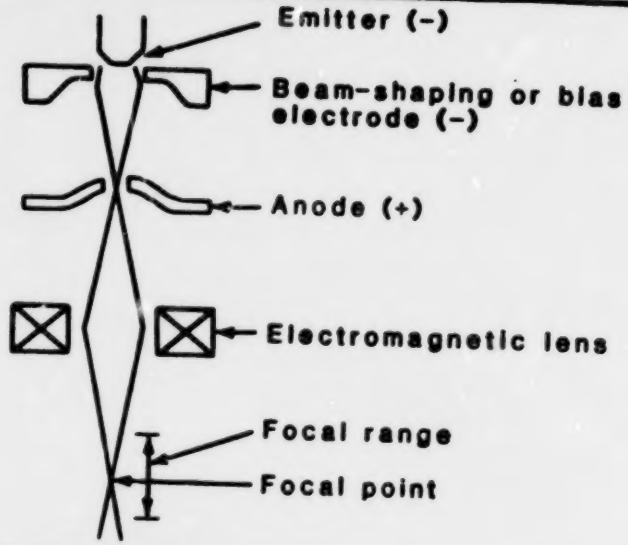


FIGURE 15 - ELECTRON BEAM GUN

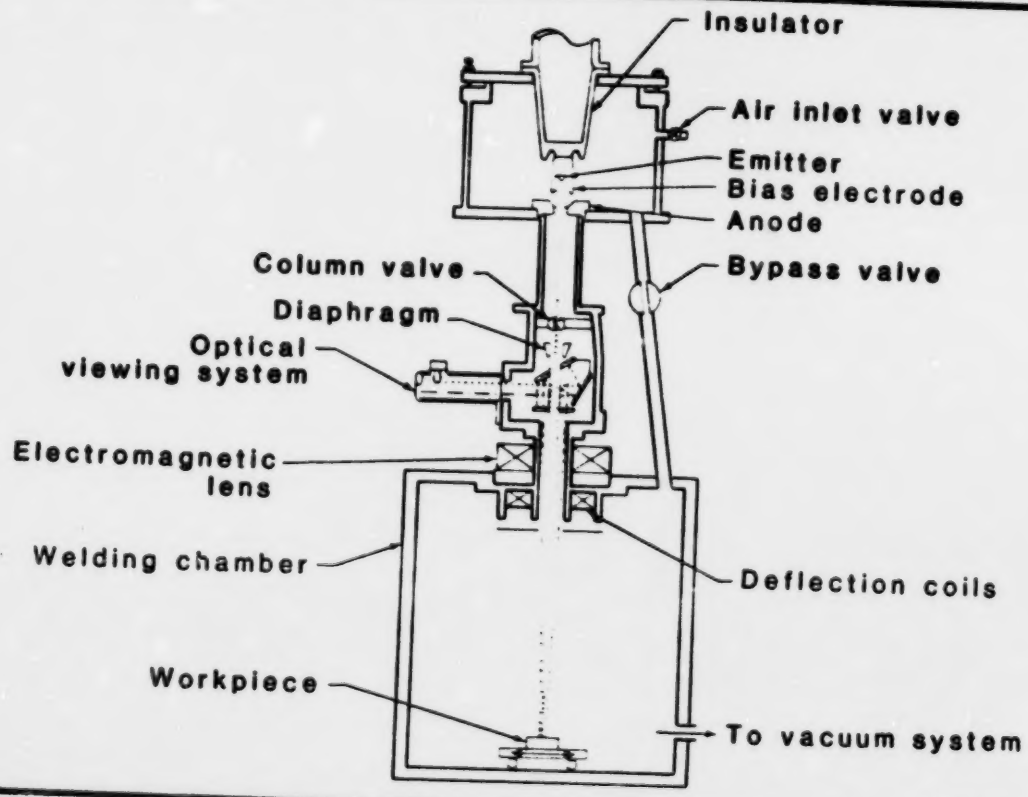


FIGURE 16 - ELECTRON BEAM WELDING MACHINE

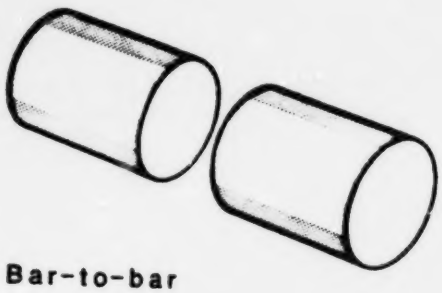
Flux, filler metal, or shielding gases are not needed, and the operation is relatively clean, with little spatter, and no arcs, fumes, or slag. The process is restricted to flat and annular butt welds that are concentric with the axis of rotation, as shown in Figure 17. One workpiece must be round (or nearly round) at the interface and must have a size and shape that can be clamped and rotated. A variation of the friction welding technique, known as radial friction welding, is under development for welding large-diameter pipelines, and involves rotation of an annular ring between the two sections of pipe to be joined (Manuel, 1981). Equipment for friction welding is normally non-portable, because the technique is best suited to special applications depending on the design and type of parts to be joined and is used for moderate- to high-volume manufacturing production.

Friction welding machines present hazards similar to those associated with machine tool lathes in that one workpiece is rotated rapidly by a drive system. Machines should be equipped with appropriate mechanical guards as well as two-hand operating switches and electrical interlocks.

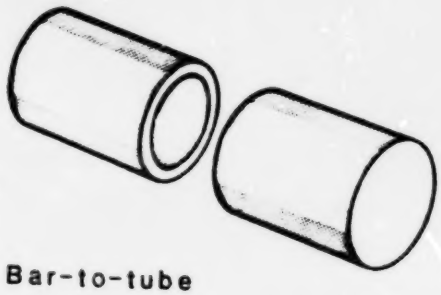
4.2.4 Flux-Cored Arc Welding

Flux-cored arc welding utilizes a continuously fed consumable electrode wire within which fluxing ingredients are enclosed as a core. Shielding is provided by the flux contained within the eletrode core and may be supplemented by externally supplied shielding gas. Flux cored arc welding is usually applied as semi-automatic welding, where the welding gun is hand-held and resembles that used in gas metal arc welding.

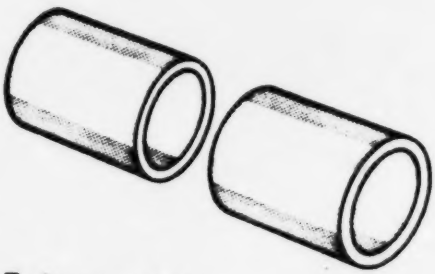
Flux cored arc welding is increasing in use for welding ferrous metals and its primary advantages are the productivity of continuous welding (as is possible with gas metal arc welding) and the benefits provided by the flux ingredients (as occurs in shielded metal arc welding). The technique is, in effect, a solution to the problem of introducing electrical current into a continuous fluxed electrode. There are two, major variations of the flux



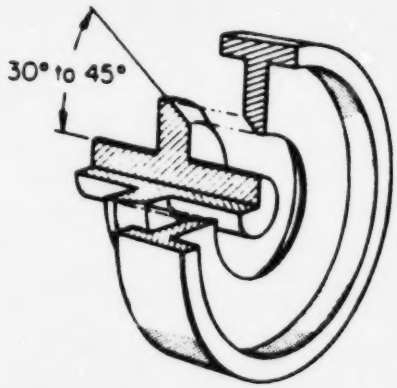
Bar-to-bar



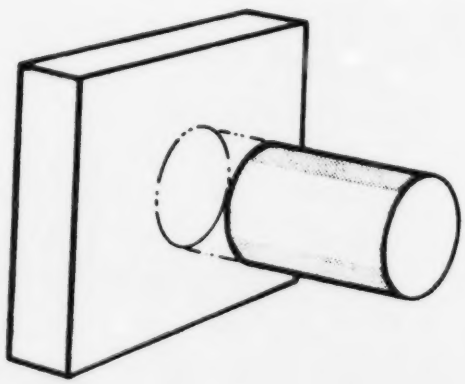
Bar-to-tube



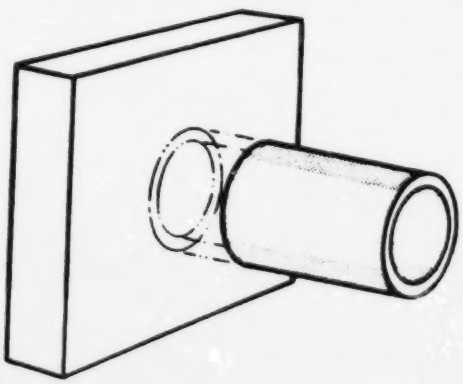
Tube-to-tube



Angular



Bar-to-plate



Tube-to-plate

FIGURE 17 - TYPES OF JOINTS COMMONLY MADE BY FRICTION WELDING

cored arc welding technique, namely, self-shielded and gas-shielded. In the former variation, the weld pool is protected by the decomposition and vaporization of the flux core in the heat of the arc, while in the latter variation, a protective gas flow is used in addition to the flux core shielding action. The self-shielded, flux-cored arc welding process is illustrated in Figure 18, and a diagram of a gun for semi-automatic, self-shielded, flux-cored arc welding is shown in Figure 19. Semi-automatic guns for use with self-shielded electrodes are light and compact.

Flux-cored arc welding (especially the self-shielded type) generates large volumes of welding fumes which require suitable exhaust equipment (American Welding Society, 1976). Self-shielded electrodes can operate in strong air currents sometimes encountered when welding outdoors or when fume-removal equipment is used. Fume extraction systems integral with the welding gun have been developed to remove fumes at the source. Smoke and fumes are collected at the arc before escaping to the atmosphere, thus greatly reducing the operator's exposure and the contamination of the workplace air (Lincoln Electric Company, 1984).

4.2.5 Adhesive Bonding

Adhesive bonding is a joining technique in which a non-metallic adhesive material is placed between the pieces to be joined, and then solidified by means of physical or chemical processes to form a bonded joint. Cleanliness of the metal surfaces to be bonded is very important, as oil or grease on the surfaces will seriously impair bonding (American Welding Society, 1976). A study of the influence of surface roughness on mechanical properties of bonded metal joints has found that fine grinding to prepare the surfaces to be joined is significantly better than coarse grinding (Gilber and Verchery, 1984).

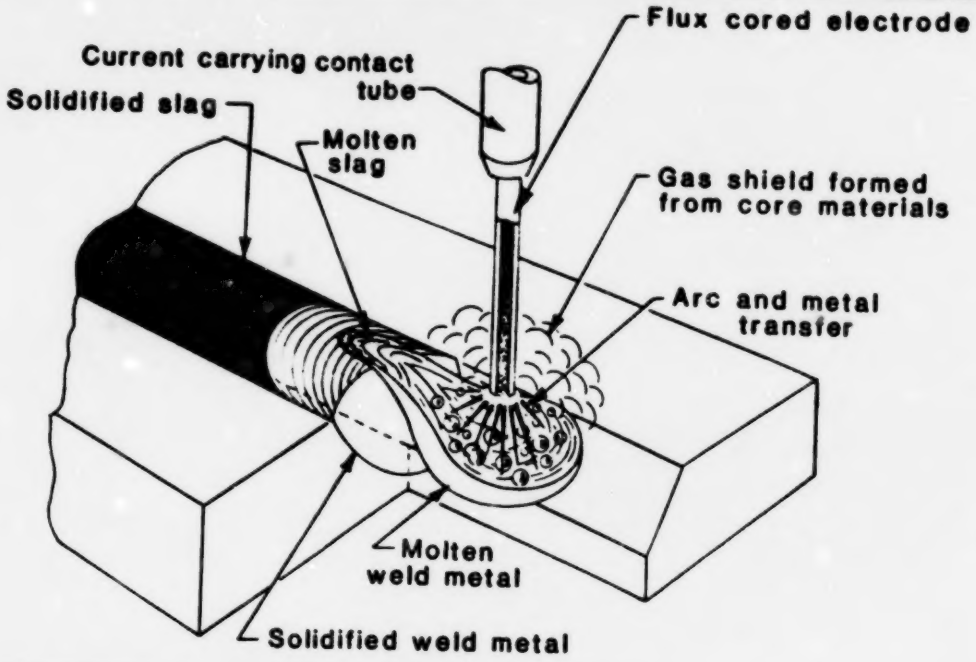


FIGURE 18 - SELF-SHIELDED FLUX CORED ARC WELDING

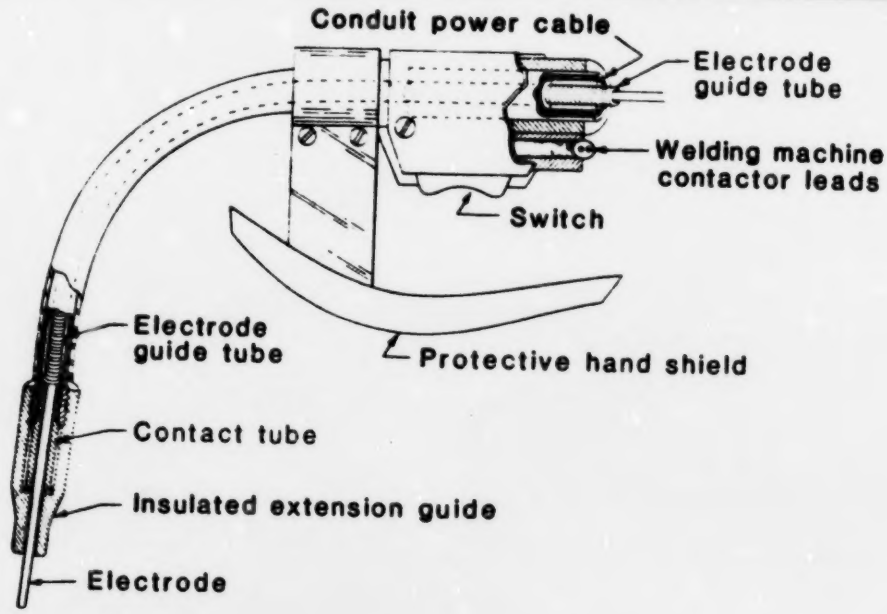


FIGURE 19 - GUN FOR SEMIAUTOMATIC SELF-SHIELDED FLUX CORED ARC WELDING

The principal advantages of adhesive bonding as a technique for joining metals arise from applications in which factors such as joining dissimilar metals, bonding thin-gauge metal, joining heat-sensitive components that would be adversely affected by soldering or brazing temperatures, and weight savings are important. Principal disadvantages of adhesive bonding techniques are related to joint performance limitations and to the need for autoclaves, presses, tooling, and other special equipment required to perform the bonding operation. Surfaces to be bonded must be properly cleaned, treated, and protected prior to bonding, and joints must be fixtured and cured at controlled temperature for some time. Although adhesive bonding is most suitable for manufacturing applications, maintenance and repair kits utilizing adhesive materials and fiberglass reinforcement tape have become available for a limited variety of patch-repair applications.

Corrosive materials, flammable liquids, volatile solvents, and toxic substances are commonly used in adhesive bonding. Severe allergic reactions can result from direct contact, inhalation, or ingestion of phenolics, epoxies, catalysts, and accelerators contained in adhesives. Careless handling of adhesives by workers may expose others to toxic materials if proper safety rules are not observed. The use of such flammable or toxic substances is incompatible with the need to eliminate combustible materials in underground coal mines and to prevent contamination of the mine atmosphere.

4.2.6 Other Emerging Techniques

A variety of other emerging metal-joining techniques exist that deserve mention, but which have such narrow ranges of application, or require such elaborate, stationary equipment, as to be clearly incapable of being adapted, through research and development, for use in underground coal mines. These techniques could be considered to include diffusion welding, plasma arc cutting, high-frequency resistance welding, explosion welding,

cold pressure welding, and ultrasonic welding. Severe limitations in terms of the thicknesses of metals that can be joined, and poor versatility, are the major obstacles which cause ultrasonic welding and explosion welding techniques to be considered generally unsuitable for the types of joints involved in underground coal mine applications. Diffusion welding, explosion welding, high-frequency resistance welding, and cold pressure welding techniques are limited seriously by their need for elaborate joint preparation and carefully engineered joint design, as is warranted only in specialty manufacturing applications (Blazynski, 1983; Crossland, 1982; Houldcroft, 1977) and are therefore seriously lacking the versatility, applications flexibility, and simplicity which are desirable in underground coal mining repair and maintenance welding.

4.3 RANKING OF EMERGING CUTTING AND JOINING TECHNOLOGIES

The various emerging technologies for joining metals, that could with research and development find application in underground coal mines, have been ranked by Robinson Dames & Moore on the basis of the technologies' relative strengths and weaknesses. Four major categories of ranking factors were considered: safety and health aspects, versatility, performance, and research and development potential. The emerging technologies considered are ranked in Table 4, by means of ranking scores that range from one to five, and for which a score of one indicates that the technique has characteristics that are most favorable (considerable strengths) and a score of five indicates that the technique has characteristics that are most unfavorable (considerable weaknesses).

The emerging techniques and technologies for cutting metals represent three fundamentally different approaches to the problem, namely, thermal cutting by a laser beam, mechanical cutting by an abrasive water jet, and mechanical cutting by means of a portable hydraulic guillotine device. These techniques cannot fairly be ranked in relation to one another because of their fundamental differences in equipment configuration and ranges of

Table 4

Ranking of Emerging Metal-Joining Techniques and Technologies

Safety & Health	Laser Beam Welding	Electron-Beam Welding	Friction Welding	Flux Cored Arc Welding	Adhesive Bonding
Fire & Ignition Risk	4	3	1	5	4
Fumes, Dust & Environmetal Factors	4	5	1	3	4
Necessity of Specialized Safety Procedures & Training	5	5	2	1	5
	13	13	4	9	13
Versatility					
Applications Flexiblity	1	1	4	2	5
Workplace Location/Portability	4	5	5	1	2
Equipment Requirements	4	5	4	2	3
	9	11	13	5	10
Performance					
Joint Preparation Requirements	3	2	4	1	5
Overall Speed	1	2	3	2	5
Joint Strength	1	1	1	2	5
	5	5	8	5	15
Research & Development Potential for Underground Coal Mining Applications					
Reduction in Safety & Health Problems	1	2	5	2	4
Increased Versatility	1	4	5	3	4
Improved Performance	2	1	5	4	1
	4	7	15	9	9
Totals	31	36	40	28	47

application. However, the hydraulic guillotine-type cutting device is clearly superior to the other two techniques considered in terms of important safety and health factors of fire risk, ignition risk, fume, dust, and environmental factors, and offers substantial advantages of portability and speed, although the technique is severely limited in terms of application flexibility.

5. PROPOSED PROGRAM OF RESEARCH, DEVELOPMENT, AND DEMONSTRATION

The review and ranking of emerging techniques for cutting and joining metals, that could with research and development find application in underground coal mines indicates that flux cored arc welding appears to offer the greatest potential for technological improvements from research and development directed towards commercial application in underground coal mines. A proposed program of research, development, and demonstration has been outlined which deals primarily with the aspects of flux cored arc welding technology that are of particular importance in respect of the safety and health hazards and concerns that are peculiar to underground coal mines.

5.1 RESEARCH

The proposed program of research would examine the state-of-the-art of flux cored arc welding techniques and equipment, to determine the status and likely improvements in the techniques' applications, flexibility, equipment portability, equipment cost, joint preparation requirements, and safety and health aspects. A literature review of the specific topics of flux cored arc welding techniques, equipment, and safety should be an initial task of the research program. The literature review would be followed by solicitation of data from manufacturers of flux cored arc welding equipment, to assess available equipment and to determine how the results of research and development conducted by the manufacturers can be expected to influence the design and capabilities of new equipment that will be introduced in the near future.

5.2 DEVELOPMENT

The development phase of the program would be performed to integrate the state-of-the-art of flux cored arc welding equipment into a demon-

stration prototype system designed with the objectives of providing for compatibility with underground coal mining safety and health risks and concerns to the maximum extent possible without unreasonably limiting the system's versatility and performance. Robinson Dames & Moore is of the opinion that development of a suitable demonstration prototype would need to include, as a minimum, means by which the following safety and health factors would be dealt with:

- The potential for the welding system to ignite explosive mine atmospheres.
- Fire hazards associated with the equipment, its power supply, hot workpieces, and molten metal/slag spatter.
- The generation of fumes, smoke, and harmful gases by the heat of the welding process on the workpiece, fluxes, filler metals, and other sources of air contaminants.
- Risks associated with handling the equipment and its components in a manner which would be typical of underground coal mining applications.

Development of such a system could be facilitated by utilizing concepts based on proven approaches to dealing with the fire, ignition, and environmental hazards of underground coal mining. The available technology for the design, construction, and testing of flameproof enclosures could, in Robinson Dames & Moore's opinion, be adapted to the development of suitable enclosure for flux cored arc welding equipment and its power supply, and could possibly be supplemented with a means of inert gas purging to allow development of a portable, flameproof welding chamber. The potential ignition source would still be present in such a system, but continuous purging of the welding chamber with inert gas could prevent an explosive mine atmosphere (methane/air mixture) from infiltrating and becoming exposed to the intense heat of welding. Removal of fumes, smoke, and harmful gases could conceivably be performed by a vacuum system that would be regulated to extract gases from the chamber at a rate slightly less than that at which purging inert gases are introduced.

Laboratory testing of the prototype demonstration system should be performed to determine its safety characteristics in relation to ignition of explosive mine atmospheres, creation of unacceptable fire hazards, release of air contaminants, creation of an oxygen deficient atmosphere caused by excessive requirements for inert gas purging, and all other underground coal mine safety and health concerns.

5.3 DEMONSTRATION

The demonstration phase of the program should begin with the specification of a series of full-scale laboratory tests that would simulate the requirements, hazards, and difficult environmental conditions typical of potential applications in underground coal mines. Individual components of the system, as well as the complete system, should undergo further testing to establish worker training requirements, safe working methods, and the equipment's ability to fail safely under conditions of abuse or misuse.

Testing of the system's performance would be accomplished during the demonstration phase by means of controlled, laboratory welding experiments on metal components and working positions typical of repair and maintenance of underground coal mining equipment. In-mine tests of such a system would not be appropriate until a need for welding and cutting in underground coal mines is convincingly established and unless the approval and recommendations of the proper regulatory authorities and testing laboratories have been obtained.

6. REGULATIONS GOVERNING FLAME CUTTING AND ARC WELDING IN CANADIAN UNDERGROUND COAL MINES, AND COMPARISON OF CANADIAN PRACTICES WITH THOSE IN SELECTED FOREIGN JURISDICTIONS

6.1 CANADA

6.1.1 Western Canada - Alberta

Flame cutting, arc welding, and brazing or soldering with open flame, are not permitted in the underground coal mines of Alberta. Robinson Dames & Moore understands that the latter regulations were put into effect two years after the adoption of the current Coal Mines Safety Regulations. Prior to that time, that type of work had been permitted under controlled conditions. However, even with careful control and very restricted use, fires were still occurring in surface facilities as a result of hot work and since it was understood that such fires would be extremely hazardous in underground mines, the regulations were revised accordingly while giving the mines a two-year grace period in which to conform.

Robinson Dames & Moore understands that the need for flame cutting and arc welding has been engineered out of underground coal mines in Alberta by having all underground equipment and materials constructed from bolted or otherwise mechanically joined components which can be removed to the surface where hot work can be performed safely. In Alberta, it is believed that the risks involved in flame cutting and arc welding in an underground coal mine are too great, and that future regulations will continue to require that the need for such work be engineered out in the mine design.

Robinson Dames & Moore notes that Alberta has moved towards the United Kingdom practices in the prohibition of flame cutting and arc welding in underground coal mines and which have not been found to be unduly onerous. Sound engineering practices in the design of equipment and its installation,

and the institution and effective implementation of routine plant maintenance procedures appear to offset the need for flame cutting and arc welding underground.

6.1.2 Eastern Canada - Nova Scotia

Robinson Dames & Moore understands that the Coal Mines Regulation Act of Nova Scotia generally excludes taking below ground any article designed or adapted to produce an unprotected flame or spark, but does permit the use of flame cutting and welding equipment as follows:

> "87 (1) An inspector may permit the use, under the constant supervision of an official carrying a locked flame safety lamp or a gas tester of a type approved by the Minister, of an electric welder, acetylene torch, or heating unit in main trolley roads, pump rooms or engine rooms, if these places are ventilated by a split of fresh air from the main intake airway.
>
> (2) The official in charge shall,
>
> (a) have any accumulations of coal dust in the place where the electric welder, acetylene torch or heating unit is to be used cleaned up and heavily stonedusted;
> (b) take steps to assure that a quantity of spare stonedust is available;
> (c) take steps to assure that fire extinguishers are available; and
> (d) make a thorough examination of the place following the completion of the work."

In the course of this study, Robinson Dames & Moore wrote to regulatory officials and to mine operators to solicit opinions on present and future Canadian needs for cutting and joining metals in underground coal mines. No opinions were submitted from Nova Scotia in response to the enquiries.

In Robinson Dames & Moore's opinion, the facility to use flame cutting and arc welding in the coal mines of Nova Scotia is considered to be required for repairs of equipment and the construction of minor fabrications as an economic alternative to carrying out these works on the surface. The

Nova Scotia Regulations provide a greater limitation on the use of flame cutting and arc welding than is permitted, for example, in the United States but the underlying reasons for continuation of the practices appear to be similar.

6.2 UNITED KINGDOM

In the United Kingdom, the Mines and Quarries Act (1954) and Regulations thereto state that no article designed or adapted to produce an unprotected flame or an unprotected spark shall be taken or used below ground in a safety-lamp mine. In effect, the Act and Regulations prohibit the use of flame cutting and arc-welding in underground coal mines.

In Robinson Dames & Moore's opinion, the prohibition of flame cutting and arc-welding in British underground coal mines has not been shown to be unduly onerous. Prior to 1970, most operating coal mines were equipped, on the surface, with electrical, mechanical, and blacksmith's work shops. All items of underground equipment which could not be repaired underground were returned to the surface for repair or overhaul. Items requiring fabrication for use underground, such as chutes, hoppers, and rail junctions, were designed and fabricated on the surface prior to installation. Such designs normally relied upon the use of bolted fasteners to join the fabricated pieces together to form complete assemblies. After 1970, as the number of operating mines diminished due to closures, Area Central Workshops serving a number of mines were established to provide the same repair and fabrication facilities previously available at individual mines.

The majority of the coal produced in the United Kingdom is won from fully mechanized longwall faces. Manufacturers of longwall face equipment normally design their equipment in modular form in which several modules are bolted together to constitute the total piece of operating equipment. When a breakdown occurs in one or more of the modules, the unit is disassembled into its individual sections and those requiring repair are returned to the

surface for overhaul while replacement components, usually obtainable through the Central Stores facility at immediate notice, are sent underground.

The British system depends heavily upon the mine manager's routine plant maintenance program both to maintain equipment in serviceable condition and to identify plant replacement and major overhaul requirements. Similarly, all new installations of underground equipment are carefully designed and evaluated such that any ancillary equipment or installation details are provided for prior to installation. It is not unusual for new equipment to be assembled and tested on the surface, prior to underground installation, to familiarize erection and maintenance personnel with the equipment and to train future operators.

Robinson Dames & Moore considers that, apart from the Mines and Quarries Act and Regulations, an inhibiting factor to the use of welding equipment in British underground coal mines has been the absence of the power facility afforded by trolley wires. Prior to 1977, only three trolley wire locomotive installations had been undertaken in Britian: Sandhole, 1953; Silverwood, 1958; and Chislet, 1963. In 1977, trolley wire locomotives were installed at Easington Colliery. Proctor and Nightingale (1983) noted that an exemption was obtained from the Mines and Quarries Act to permit the use of thermit welding to bond heavy copper earthing wire to the ends of the rails. Traditional methods of welding were rejected due to the difficulty of actually forming the joints in-situ, the need to use heavy electrical equipment or gas cylinders, and the possibility of causing metallurgical damage to the rails. Thermit welding was preferred to explosive welding due to the extreme degree of cleanliness required to obtain a satisfactory explosive-welded joint.

In summary, flame cutting and welding are not permitted in British underground coal mines unless a specific exemption is obtained. In Robinson Dames & Moore's opinion, the prohibition is not unduly onerous since greater

reliance is placed on routine plant maintenance, detailed pre-installation design and fabrication, and on the availability of replacement modules to original equipment manufacturer specifications.

6.3 UNITED STATES

In the United States, the Code of Federal Regulations, Title 30, Part 75 - Mandatory Safety Standards - Underground Coal Mines, states as follows:

> "§75.1106 Welding, cutting, or soldering with arc or flame underground.
>
> [STATUTORY PROVISIONS]
>
> All welding, cutting or soldering with arc or flame in all underground areas of a coal mine shall, whenever practicable, be conducted in fireproof enclosures. Welding, cutting, or soldering with arc or flame in other than a fireproof enclosure shall be done under the supervision of a qualified person who shall make a diligent search for fire during and after such operations and shall, immediately before and during such operations, continuously test for methane with means approved by the Secretary for detecting methane. Welding, cutting, or soldering shall not be conducted in air that contains 1.0 volume per centum or more of methane. Rock dust or suitable fire extinguishers shall be immediately available during such welding, cutting or soldering."

Further restrictions on flame cutting and arc welding in underground coal mines in the United States are contained in the National Bituminous Coal Wage Agreement of 1981, between the United Mine Workers of America and the Bituminous Coal Operators Association, as follows:

> "Article III -- The Employer shall prohibit cutting, welding or burning in the face areas of any underground mine when any miners are inby unless the contaminated air is immediately directed into a return air course, or unless the cutting, welding or burning is far removed from the working areas so as to present no hazard to the men inby."

In 1985, the Mine Safety and Health Administration (MSHA) reported that welding and cutting operations comprised 36 percent of the causes of fire-related accidents (Coal Mining and Processing, 1984). A review of reportable accidents from January 1, 1980 to December 31, 1983 indicated that a similar number of accidents occurred each year and that the types of accident were also similar. Flying metal particles accounted for many of the accidents that occurred during welding operations, particularly eye injuries and radiation burns from the welding arc. Cutting operation accidents included burns to the person using the torch and to a person in proximity to the user, smoke inhalation, and clothing catching fire. MSHA recommended a review of present work practices and the adequacy of job task training, and stressed the need for proper use of protection devices, training, and examination of equipment.

The facility enabling the use of flame cutting and arc welding in underground coal mines in the United States, afforded by the Code of Federal Regulations, has been extensively used by coal mine operators for minor and major repairs of underground equipment, fabrications, and haulage track joints and crossings. Power sources from the trolley-wire haulage systems, installed in many mines, have been readily available. The coal mining industry is market-orientated and cost competitive and, particularly in the Eastern United States, coal is produced from a great many small mines which would be uneconomic if required to provide adequate surface facilities and inventory for the repair, maintenance, or replacement of underground equipment which, currently, can be retained in service by the use of flame cutting or arc welding procedures.

In Robinson Dames & Moore's opinion, the general mining conditions and mining environment, and the structure of the coal mining industry, in the United States is substantially different from that in the United Kingdom and, particularly, Eastern Canada. A prohibition of flame cutting and arc welding in the United States would, in Robinson Dames & Moore's opinion, have profound effects on the structure of the industry and the economics of

coal production. However, it may not be construed that Robinson Dames & Moore condones the use of flame cutting or arc welding in underground coal mines of the United States, since it considers that the high incidence of reportable welding-related accidents is unacceptable.

7. EXISTING AND FUTURE NEEDS AND FREQUENCY OF FLAME CUTTING AND ARC WELDING IN CANADIAN UNDERGROUND COAL MINES

7.1 EXISTING NEEDS AND FREQUENCY

Regulations that effectively prohibit welding or cutting with arc or flame in underground coal mines in Alberta are contained in Part 3, Division 16, of The Coal Mines Safety Act - Alberta Regulation 333/75 - Coal Mines Safety Regulation (Government of the Province of Alberta, 1975). The regulation has been dealt with by means of suitable engineering of underground equipment and metal structures such that they are assembled from bolted or otherwise mechanically joined components which can be removed to the surface where arc welding and flame cutting can be performed safely. As a result of efforts to comply with the regulation, the need for flame cutting and arc welding in underground coal mines in Alberta has been avoided and, in practical terms, no longer exists.

In underground coal mines in Nova Scotia, flame cutting and arc welding are restricted by the Coal Mines Regulation Act of Nova Scotia to the following underground locations: main trolley roads, pump rooms, and engine rooms. The regulations require that for flame cutting or arc welding to be performed, these places must be ventilated by a split of fresh air from the main intake airway, and that such work requires the permission of an inspector, constant supervision by an official carrying an approved means of detecting methane, clean-up and stone-dusting of the work area, provision of fire extinguishers and spare stone dust, and thorough examination of the place following completion of the work.

As part of this study, Robinson Dames & Moore wrote to regulatory officials and mine operators to solicit opinions on present and future Canadian industry needs for flame cutting and arc welding in underground coal mines. No opinions were received from Nova Scotia in response to the

inquiries. In Robinson Dames & Moore's opinion, the facility to use flame cutting and arc welding in Nova Scotia underground coal mines is considered to be required primarily for repairs of equipment components that can be removed to the underground locations to which such work is restricted. Since components which require flame cutting or arc welding, and which can be removed to a "safe" underground location where such work is carried out, could conceivably be removed to the surface without unreasonable difficulty, it is apparent that flame cutting and arc welding are performed underground largely as a matter of convenience rather than as a means of dealing with an unavoidable, existing need.

7.2 FUTURE INDUSTRY NEEDS

Underground coal mining equipment is being designed with increasing use of high-strength, low alloy (HSLA) steels (Welding Design and Fabrication, 1980). It is expected that new HSLA steel applications will slowly move into structural welding where it is desirable to reduce size and weight of structural components (Olson and Mueller, 1977). Requirements for pre-heating and post-weld treatment to minimize metallurgical problems in the heat-affected zone of welded joints, and the desirability of non-destructive testing of weld integrity will tend to diminish the future need for and applicability of welding underground.

Robinson Dames & Moore notes that the increasing importance and application of remote ventilation monitoring systems that rely upon measurement of carbon monoxide concentrations in the mine atmosphere, to detect sponteneous heatings or other fire incidents, may make it highly undesirable to use flame cutting or arc welding underground. Carbon monoxide is contained in the combustion products of the oxygen-fuel gas flame as used in flame cutting, and the flame cutting process consumes considerable quantities of oxygen from the atmosphere thereby creating an oxygen-deficiency situation. Arc welding using coated or self-shielded flux cored electrodes, which produce their own shielding gases, produce carbon

monoxide as one of the shielding gases formed as cellulose in the electrode covering or core decomposes as the electrode is consumed. Robinson Dames & Moore considers that practices which create carbon monoxide or oxygen-deficiency could cause ventilation monitoring equipment to give misleading readings which could make early detection of spontaneous heatings or other fire incidents more difficult. The future need for underground flame cutting and arc welding must be weighed against the possible incompatibility of such practices with the more important future needs for mine ventilation monitoring.

Sound engineering practices in the design and installation of underground mining equipment and facilities, and the institution and effective implementation of routine plant maintenance procedures should be relied upon to prevent future needs for underground flame cutting and arc welding from arising. Examination of the approach to the problem, taken in underground coal mines in Alberta and especially the United Kingdom, indicates that future needs for flame cutting and arc welding in Canadian underground coal mines can be obviated, with corresponding avoidance of associated risks, if new equipment and metal fabricated structures to be brought into the mines are given thorough prior study by mine management, maintenance supervisors, and mining and mechanical engineers, to ensure that the alternatives that have been developed and utilized so successfully in the past in Alberta and the United Kingdom will continue to be sufficient.

8. SUMMARY OF CONCLUSIONS

Robinson Dames & Moore has conducted a review of available technology, industry needs, and research opportunities for cutting and joining metals in Canadian underground coal mines. The study considered the strengths and weaknesses of available cutting and joining techniques in terms of their safety and health hazards, versatility, and performance. In relation to other available techniques for joining metals, mechanical fastening appears to present the least risks in terms of underground coal mine hazards of fire, ignition of an explosive atmosphere, and worker exposure to fumes and other environmental factors. Of the available techniques for cutting metals, the least mining safety and health risks appear to be associated clearly with mechanical cutting techniques. Although it is noted that mechanical fastening and mechanical cutting techniques may, in some applications, lack the versatility or performance of welding or thermal cutting techniques, Robinson Dames & Moore considers that any performance or versatility disadvantages of the mechanical techniques are of far lesser importance than the considerable safety and health advantages that result from the avoidance of risks associated with flame cutting and arc welding.

Emerging technologies for cutting and joining metals were reviewed, and their strengths and weaknesses were considered in terms of mining safety and health risks, versatility, performance, and research and development potential for underground coal mining applications. High-pressure water jet cutting and hydraulic guillotine-type cutting represent alternatives to flame cutting that offer substantial reduction in mining safety and health risks and could be suitable for a variety of underground coal mine applications. Emerging joining techniques of laser beam welding, electron beam welding, friction welding, flux cored arc welding, and adhesive bonding were reviewed. A program of research, development, and demonstration was proposed for bringing the most promising technology, flux cored arc welding (with integral fume removal), to commercialization. Robinson Dames & Moore

emphasizes, however, that the need for use of welding techniques in underground coal mines may be eliminated by the application of sound engineering practices in the design and installation of underground mining equipment and facilities to ensure that they can be assembled from bolted or otherwise mechanically joined components which can be removed to the surface where welding can be performed far more safely and effectively.

The need for flame cutting and arc welding effectively has been eliminated from underground coal mines in the United Kingdom and Alberta. The use of flame cutting and arc welding in underground coal mines located in jurisdictions that permit such practices (such as the United States and Nova Scotia) is as a matter of operating convenience rather than an unavoidable existing need. Future industry needs for flame cutting and arc welding in Canadian underground coal mines can be obviated, with corresponding avoidance of associated risks, if the available alternatives that have been developed and utilized so successfully in the past in Alberta and the United Kingdom are adopted.

APPENDIX A

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